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The Potential of Types and Positions of Window Blinds on Energy Performance in Residential Buildings in Najran city

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DEDICATION

We dedicate our research work to our families and many friends who always support us with their love, patience, encouragement, and constant prayers. Special heartfelt gratitude is given to our beloved parents, whose words of encouragement and push for tenacity ring in our ears.

Finally, we are deeply grateful to all our brothers, sisters, friends, and everyone who had a role in making this possible.

APPROVAL SHEET

This project report entitled **“The Potential of Types and Positions of Window Blinds on Energy Performance in Residential Buildings in Najran city"** was prepared and submitted by (Abdullah Hamad AL-Bisher - ALI HAMAD HADI KOZMAN BALHARETH - OSAMA ABDU MOHAMMED ALMOBARKI) as the Partial fulfillment of the requirement for the Bachelor of Engineering (**Architectural Engineering**) is as a result of this accepted.

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The Potential of Types and Positions of Window Blinds on Energy Performance in Residential Buildings in Najran city

ABSTRACT

Residential buildings in the Kingdom of Saudi Arabia consume about 50% of the energy produced in the Kingdom. This energy's primary goes to the air conditioning that consumes 70% of residential building consumption value. The increase of energy consumption, especially in the residential sector, increases emissions of CO2 and gases that have a significant role in the greenhouse effect.

Buildings need careful design in such a climate of Najran city. In a hot arid climate, building envelopes, particularly the windows, play a central role in heat gain. During heat transfer, there are many intricate processes, including direct heat gain and heat transfer due to the temperature variation between outdoor and indoor. Advanced glazing, such as (LOW-E) glass, reduces energy consumption by 30 to 50 percent compared to ordinary windows. However, Low-E glass, as cited in previous studies, show weakness in controlling direct solar radiation.

Reviewing previous studies on window design in Saudi Arabia shows that people are more interested in privacy more than anything else they need. Talking about shading devices are useful in balancing between heat controls and obtaining privacy. The study concerns on window design integrated the curtains.

However, failure in selecting the right type and position of curtains may cause an increased heat gain. The study aimed to review window blinds' type and position to reduce direct solar heat gain and eventually the energy consumption in residential buildings of

Najran city; a hot-arid climate. It is also to **examine** (simulation) the impact of positions and types of window-blinds on reducing energy consumption through windows. DesignBuilder will simulate the different proposed systems in different orientations reaching the optimum system of each orientation. In achieving the main objectives, the study simulated a selected villa and examining the impact of low-e glass in controlling heat gain and then the impact of window- blinds in controlling the direct solar heat gain on east/west fenestrations. The impact of type and position of blinds on energy consumption are also simulated in a selected villa. Making the blinds as useful solution, the study first suggest a Clear Low-e glass to replace the current wired-glass for outdoor connection and heat control. WWR of 20% instead of 6% to enhance the building daylighting. The study suggest an operation scheduled of window blinds to enhance energy savings.

The study found that the outside position of the roller blinds integrating with low-e glass are best than other types in reducing energy consumption by about 16%. Comparing inside-blinds to the reference case of WWR 20% clear glass, the energy consumption was increased by about 10%. Smart blinds like Electrochromic makes a useful reduction of about 16% compared to the reference case.

CHAPTER 1

INTRODUCTION

1.1 Background

Windows in buildings is a critical component because it crosses the direct point of contact between the interior and exterior of the building, and therefore it is an essential component of the heat control and control of the transfer of heat from the outside of the building to the interior. If the windows do not design well, then buildings need to maintain the indoor environment using a mechanical way that will lead to a high consumption of energy, which in turn will cause an increase in carbon dioxide emissions that will cause an increase in the temperature of the area surrounding the building, and then the rise in the neighborhood temperature that will lead to a rise in temperature in the city and so on. The emitted gases will also lead to significant environmental problems that make a living and environmental stability not good. Thus, we will be an unhealthy community psychologically and physically.

Window design is essential in a hot climate. Integrating window curtains is also a fundamental issue that needs careful design and careful selection of the type and position. Failure in selecting the right type and position of curtains may cause an increase in heat gain. As we know, the local market produces many types of curtains, including the interior and exterior, also the cloth and plastic, and some of which are automatic; this affects the speed of heat transfer and the amount of heat transmitted that may make the energy consumption increase and the health, psychological and material losses also increase.

1.2 Problem Statement and Motivation

Residential buildings consume a large amount of energy, specifically air-conditioning and lighting systems of all kinds in residential buildings. Therefore, a solution must be found and improving and developing residential buildings' performance to save energy. We have previously talked about the fact that energy consumption in the Kingdom of Saudi Arabia is enormous, especially in the residential sector. Window design playing a significant role in heat gain. Designing windows in residential buildings need balancing between heat control, outside connection, and residents privacy. Window shading may play the right role in this issue. Failure in selecting the right type and position of curtains may cause an increase in heat gain.

However, the research question raised here is:

- What are the window systems that integrate blinds and reduce home privacy and energy savings in the residential building in Njran City?
- How could the type of window blinds reduce heat gain through windows in different orientations in Najran climate?
- How could the position of window blinds reduce heat gain through windows in different orientations in Najran climate?
- How the type and position of window blinds could integrate outside connection (including daylight), home privacy, and heat gain control?

1.3 Aim and Objectives

Reducing energy consumption in buildings is very important, especially in residential buildings, where air conditioning and electrical lighting are the primary consumers of energy in a residential building because the heat transmitted through windows causes an increase in air conditioning loads, so the objectives of this study are: -

- To review the type of window blinds that could reduce heat gain through windows in hot climate orientations?
- To conduct a questionnaire survey on the occupants' preference related to window design in Najran city.
- To investigate (simulation) the impact of window-blinds-**positions and types integrated with a double low-e glazing,** in reducing both direct solar heat gain (blinds) and heat gain due to the variation between outdoor and indoor (low-e glazing) in Najran city.

1.4 Scope of Project

This study examines the main effect of the types and position of window blinds and their role in controlling solar heat gain and daylight inside residential buildings to control energy consumption and limit its growth in the city of Najran, which is one of the hot and dry areas in the Kingdom of Saudi Arabia.

1.5 Project Organization

To achieve the objectives mentioned above, the research was divided into seven chapters.

Chapter 1: The introduction summarizes the fundamental research and gives a clear picture of the statement of the research problem, the importance of covering the specific research problem, and how the research objectives lead to sufficient knowledge that covers the topic of the research, the effect of glass types on the level of acquisition and heat transfer and the impact of window blinds and their shading in residential buildings In Najran.

Chapter 2: Literature review, this chapter covers the subject area information and reviewing various research studies to identify the effect of the types of window system and the types of window blinds and their shading on the level of solar heat gain and transportation and the level of daylight lighting and reduce energy consumption in residential buildings in the hot, dry climate, in Najran.

Chapter 3: The separation methodology will determine the appropriate way to investigate the impact of type and position of window blinds in a residential building on the energy consumption, the heat gain, and the light entering the residential buildings using energy simulation programs in the buildings, their types, and the type that was chosen to work on in the Najran region.

Chapter 4: collecting data on the case study, which is (Najran housing project). Moreover, surveying the occupants.

Chapter 5: will cover the base case modeling. Adopting a case study was investigated in previous student's projects.

Chapter 6: The results and discussion. This chapter will include four phases:

- Phase 1: type of window blinds
- Phase2: position of window blinds
- Phase3: simulation
- Then the optimum case.

Chapter 7: conclusion and recommendations.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

This section contains the literature review of all related information, components, theories, equations, studies, facts, and other relevant sources used to complete this project. These reviews will be the principal references in the study of windows' energy performance in residential buildings, considering the type and position of blinds in the hot arid climate of Najran.

2.2 INTRODUCTION TO ENERGY CONSUMPTION IN SAUDI ARABIA

In this research, we will discuss energy consumption in the Kingdom of Saudi Arabia; then, we will focus on energy consumption in residential buildings in particular. According to the Saudi Center for Energy Efficiency's introductory bulletin, three main sectors represent the largest energy consumer in the Kingdom of Saudi Arabia, namely industry, transport, and buildings, where it consumes more than 90% of the Saudi energy produced. The industrial sector consumes about 42% of the energy in the Kingdom of Saudi Arabia, while the transportation sector's consumption rate is about 23% of the total energy consumption. The buildings sector in Saudi Arabia owns about 23% of the total energy consumed in the Kingdom, of which about 70% goes to air conditioners, in the absence of 70% of the buildings being thermal insulation, as thermal insulation contributes to reducing energy consumption in air conditioners by 30%. Worldwide, several countries are spending on renewable energy sources to save natural resources for a sustainable future. In the Kingdom of Saudi Arabia (KSA), electricity consumption uses over one-third of the country's total daily oil production, as shown in Figures 1 and 2. So, the KSA government has become concerned about its future economy and is spending on sustainability measures (Ahmed Felimban, 2019).

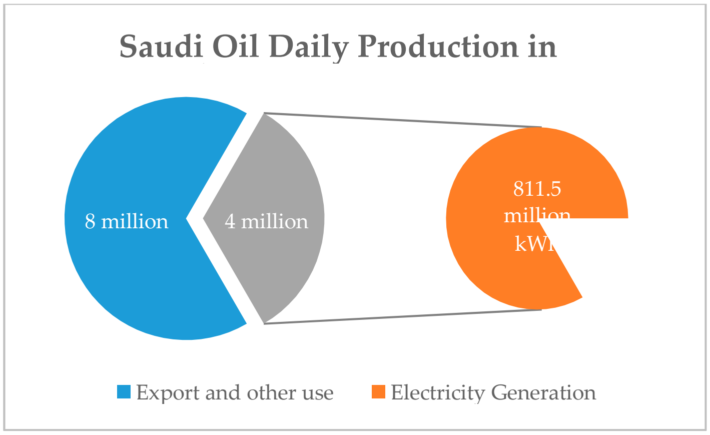


Figure1: Electricity percentage from daily oil production. Source

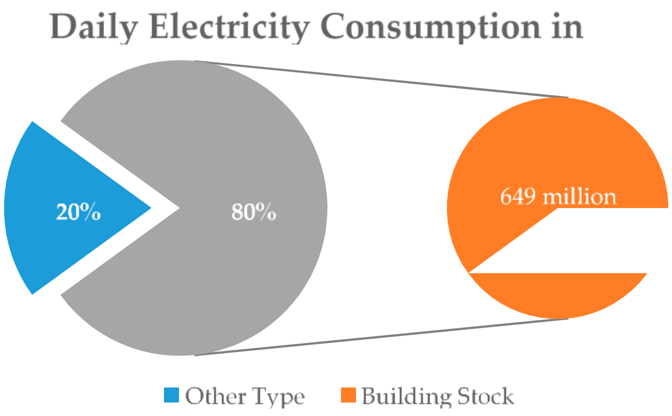


Figure2: Electricity consumption of the building sector.

Increasing energy demand drives higher greenhouse gas emissions rates, which have been recognized as the main reason for global warming and the many problems correlated with climate change. Those issues began more significant works among countries and international organizations to balance energy generation with energy needs while contemplating environmental consequences. The balance between energy generation and need should focus on generating the required energy and improving energy efficiency to ensure sustainable energy provision. At the World Energy Congress (Special ISO Focus 2007), the International Organization for Standardization (ISO), the IEA and the European Committee for Standardization (CEN) issued strategic and operational directions for energy efficiency in buildings. After the 21st Conference of the Parties (COP21) — Paris in December 2015, the IEA issued a report "Energy and Climate Change" in which the agency estimated that world energy demand is responsible for two-thirds of the world's anthropogenic greenhouse gas emissions and urged countries to promote sustainable energy policies that incentivize economic growth and environmental protection in a global context ((OECD/IEA, 2018)

2.2.1 Energy consumption in KSA

The Kingdom of Saudi Arabia (KSA) is the largest oil producer worldwide by 13.2%, as well as the largest oil ranked 14th worldwide in energy consumption per capita, according to the IEA's Energy Indicators report for 2014 (International Energy Agency IEA n.d.). Moreover, the energy consumption per capita has rapidly escalated, from 57.92 MWh in 2004 to 80.36 MWh in 2014 (International Energy Agency IEA n.d.), for an increment of 38.8% in one decade. Such increases require dynamic extension of support, primarily in the residential building sector. However, in the context of approximately low energy costs, energy efficiency has not been a high priority throughout the different phases of Saudi buildings' life cycle (design, construction, and use). About 5.5 × 106 residential buildings in the KSA (94% of the total residential buildings) are connected to the national electricity grid, out of them 0.272 × 106 in the Qassim region (Household Energy Survey 2017).

Therefore, most of the energy demand of these buildings is provided by electric power, as shown in Table 1. As demonstrated in this table, the reliance on residential buildings on electricity to meet energy demands is increasing year by year, which resulted in a consistently increasing trend in electrical energy consumption in the KSA yearly. This trend in electrical energy usage in the KSA is not reflected in countries in the same region with similar lifestyles, such as the United Arab Emirates. According to data published by the IEA (International Energy Agency IEA n.d.), electrical energy consumption per capita in the KSA increased from 6.11 MWh in 2004 to 9.41 MWh in 2014. This consumption is considerably higher than the world average of 3.030 MWh/capita in 2014. The ratio of residential electricity consumption is about 50%, which is also relatively high compared with the worldwide average of less than 27% (RADHWAN ALMASRY, 2020).

Table 1 Reliance on electricity for residential energy consumption in the KSA

	1990	1995	2000	2005	2010	2011	2012	2013	2014
Reliance (%)	74	77.0	80	82	85	84	86	87	88

Currently, residential buildings consume around half of the building stock's total energy consumption due to many building code defects, design processes, urban design, and construction applications.

Research has illustrated the significant challenges that KSA buildings are facing, such as high electricity consumption, mainly due to air conditioning (A.C.) units, which are responsible for up to 70% of the electricity consumption of residential buildings, and a lack of insulation in the building envelope (70% of residential buildings are not thermally insulated. A governmental report showed that refrigerators used twice as much electricity as A.C.s in the average week. However, the report did not show any energy measurement values that we can be compared, such as kWh (Kilowatts per hour). Existing studies do not include the actual energy consumption from all energy users and do not show the building envelope's role in using energy. Unfortunately, the country's recent changes and developments are also not included in any of these studies. Thus, there is a need to identify the leading causes of the high energy consumption of buildings. This study has generated a survey with specific criteria that can show the current buildings' energy consumption and its users' behavior. No previous studies have considered user behavior and what its effects are on energy consumption.

The key driver for energy consumption is the hot–arid climate, which requires the cooling of buildings to provide the desired indoor comfort. Lower fossil fuel consumption requires immediate improvement in buildings' energy performance for efficient energy use to avoid future economic consequences in the country (MUHAMMED ASIF, 2014).

This article aims to evaluate the effect of the current users' behavior on the buildings' energy performance and considers the cost aspects. It was challenging to produce more detailed questions in the survey regarding energy consumption. This type of electronic questionnaire only recorded complete questionnaires; partly completed questionnaires were disregarded. It was also not possible to distinguish, in-depth, how the electricity per household was consumed, such as in cooling, heating, cooking, cleaning, and ironing. The main reason for this is to understand and identify the leading causes of high energy consumption in buildings. The study used a survey with specific criteria to assess current buildings' energy consumption and the relationship with its users' behavior (MUHAMMED ASIF, 2014).

Table 2 Energy Balance in electricity, crude oil and natural gas in Saudi Arabia and Europe

Electricity	total	Saudi Arabia per capita	Compared to Europe per capita
Own consumption	296.20 bn kWh	8,789.33 kWh	5,510.65 kWh
Production	324.10 bn kWh	9,617.23 kWh	5,924.84 kWh
Crude Oil	Barrel	Saudi Arabia per capita	Compared to Europe per capita
Production	10.43 m bbl	0.309 bbl	0.005 bbl
Export	7.34 m bbl	0.218 bbl	0.004 bbl
Natural Gas	Cubic meters	Saudi Arabia per capita	Compared to Europe per capita
Own consumption	109.30 bn m³	3,243.33 m³	903.33 m³
Production	109.30 bn m³	3,243.33 m³	456.57 m³

Table 3: Carbon footprint in Saudi Arabia compared to Europe

	CO2 emissions in 2014	**Saudi Arabia per capita**	**Compared to Europe per capita**
Total	601.05 m t	19.44 t	6.38 t
› of which diesel + gasoline	413.23 m t	13.37 t	2.63 t
› of which natural gas	159.26 m t	5.15 t	1.55 t
› other sources	28.56 m t	0.92 t	2.20 t

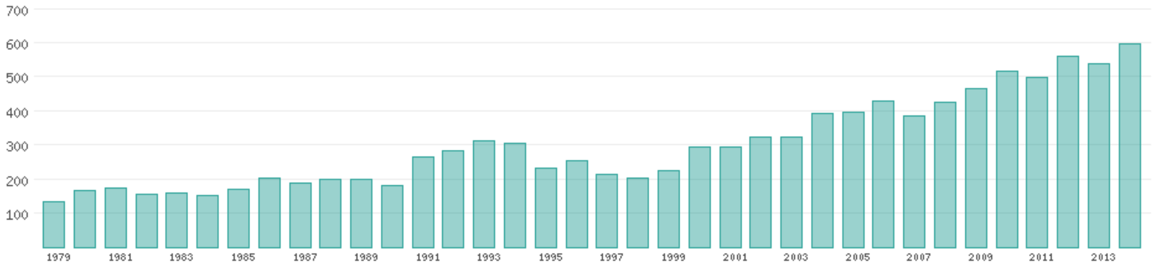


Figure3: Development of CO2 emissions from 1979 to 2014 in a million tons

2.2.2 Production capacities per energy source

The given production capacities for electric energy have a theoretical value, which could only be obtainable under ideal conditions. They measure the generatable amount of energy that would be reached under permanent and full use of all power plants' capacities. In practice, this is not possible because, e.g., solar collectors are less efficient under clouds. Also, wind- and water-power plants are not always operating under full load. All these values are only useful concerning other energy sources or countries.

Table 4: showing the production capacities for different energy sources in Saudi Arabia compared to Europe.

Energy source	total in Saudi Arabia	percentage in Saudi Arabia	percentage in Europe	per capita in Saudi Arabia	per capita in Europe
Fossil fuels	726.55 bn kWh	100,0 %	49,2 %	21,559.51 kWh	8,114.79 kWh
Nuclear power	0.00 kWh	0,0 %	7,0 %	0.00 kWh	1,154.21 kWh
Water power	0.00 kWh	0,0 %	24,1 %	0.00 kWh	3,976.91 kWh
Renewable energy	0.00 kWh	0,0 %	19,7 %	0.00 kWh	3,274.18 kWh
Total production capacity	726.55 bn kWh	100,0 %	100,0 %	21,559.51 kWh	16,488.68 kWh

2.2.3 Usage of renewable energies

Renewable energies include wind, solar, biomass, and geothermal energy sources. This means all energy sources that renew themselves within a short time or are permanently available. Energy from hydropower is only partly renewable energy. This is undoubtedly the case with river or tidal power plants. Otherwise, numerous dams or reservoirs also produce diverse forms, e.g., by pumping water into their reservoirs at night and recovering energy from them during the day when there is an increased demand for electricity. Since it is impossible to determine the amount of generated energy, all hydropower energies are displayed separately.

In 2015, renewable energies accounted for around 0.0 percent of actual total consumption in Saudi Arabia.

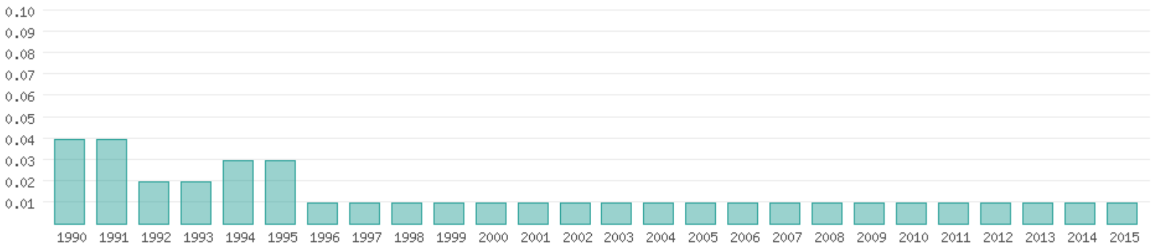


Figure4: The following chart shows the percentage share from 1990 to 2015:

2.3 Introduction to the principles of heat transfer

People have always understood that something flows from hot objects to cold ones. This is called a heat flow. In the eighteenth and early nineteenth centuries. Scientists imagined that all bodies contained an invisible fluid, which they called Caloric Was assigned a variety of properties, some of which proved to be inconsistent with nature (e.g., it had weight and could not be created nor destroyed). (TEXTBOOK :. A.)

If someone leaves the room. Some small buoyancy-driven (or convective(air motion will continue because the walls can never be perfectly isothermal. Such processes go on in all plant and animal life and the air around us. -my occur throughout the earth. "which is hot at its core and cooled around its surface, 'The only conceivable domain free from heat now would have to be isothermal and isolated from any other region. It would be -dead" in the fullest sense of the word — devoid of any process Of any kind. (TEXTBOOK :. A.)

2.3.1 Heat transfer in building:

2.3.1.1 Building Envelop

A passive solar home is an exceptional home, differing from standard construction in its shell's thermal integrity and well-considered design.

The design options, employing the principles and methods described here, are endless.

However, artistry is always essential when installing insulation, air sealing the building envelope, and installing the windows.

Most successful passive solar homes are very airtight. They may require mechanical ventilation systems to main-The thermal mass used include a masonry floor, a masonry wall bordering the house, or water containers. The house's heat distribution can be accomplished through ceiling and floor level vents, windows, doors, or fans. Most homeowners and builders separate the sunspace from home with doors and windows so that home comfort is not overly affected by the sunspace's temperature variations.

Sunspaces may often be called, and look a lot like "greenhouses." However, a greenhouse is designed to grow plants, while sunspace is designed to provide heat and aesthetics to a home. (GTBARIA)

Many greenhouse design elements, such as overhead and sloped glazing, which are optimized for growing plants, are counterproductive to an efficient sunspace. (GTBARIA)

Moisture-related mold and mildew, insects, and dust inherent to gardening in a greenhouse are not mostly compatible with a comfortable and healthy living space.

Also, to avoid overheating, it is difficult to shade sloped glass, while a properly sized overhang can shade vertical glass. (GTBARIA)

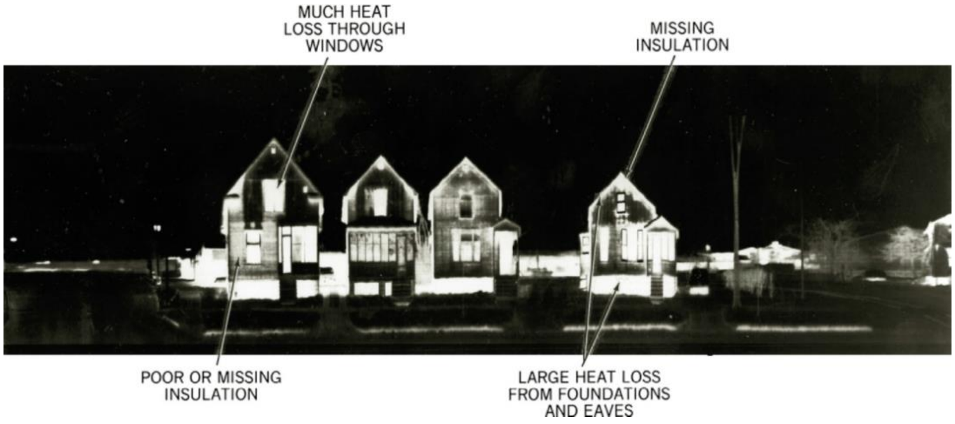

MUCH HEAT LOSS THROUGH WINDOWS
MISSING INSULATION
POOR OR MISSING INSULATION
LARGE HEAT LOSS FROM FOUNDATIONS AND EAVES

Figure5: Different problem of heat loss

Thermography can pinpoint the weakness in the thermal envelope. This winter thermogram indicates the warmest areas, which are a result of the most significant heat loss. (Vanscan [Thermogram] by Daedalus Enterprises, Inc(. (GTBARIA)

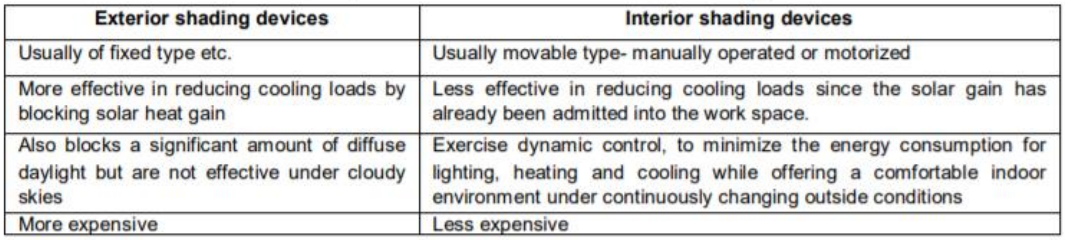
2.3.1.2 Heat transfer through windows

Shading devices and coated or tinted glass can be used to control heat transfer through windows. Gouri Datta [14] studied the thermal performance of buildings for four different cities in Italy and concluded that external fixed horizontal louvers of proper design for south windows were effective in not only reducing cooling loads of a building in summer but also reduced overall annual primary energy loads of a building.

Shading devices used to control heat transfer may be the integral parts of the building, i.e., architectural solutions, or industrially manufactured devices, such as window treatments or shading and coating. The category of architectural solutions includes overhangs and vertical fins, window set-back, light shelves.

Whereas window treatments include a variety of devices that are attached to the exterior (awnings, Italian awnings, exterior Venetian blinds, overhangs, baffle Proc. of the International Conference on Advances in Mechanical Engineering, August 3-5, 2009 S.V. National Institute of Technology, Surat – 395 007, Gujarat, India Screens or interior (Venetian blind, screen, roller blind,) of windows. As shown in Table 5 presents a comparison of exterior and interior shading devices. (Sharda, Sudhir Kumar , & Kurukshetra Haryana)

Table 5 Comparison between exterior and interior shading devices. (Sharda, Sudhir Kumar , & Kurukshetra Haryana)



Exterior shading devices	Interior shading devices
Usually of fixed type etc.	Usually movable type- manually operated or motorized
More effective in reducing cooling loads by blocking solar heat gain	Less effective in reducing cooling loads since the solar gain has already been admitted into the work space.
Also blocks a significant amount of diffuse daylight but are not effective under cloudy skies	Exercise dynamic control, to minimize the energy consumption for lighting, heating and cooling while offering a comfortable indoor environment under continuously changing outside conditions
More expensive	Less expensive

Although heat gain in a building is similar to heat loss, some significant differences exist. Similar to winter, there is heat gain by transmission, infiltration, and ventilation. However, unlike winter, there is also heat gain due to internal heat sources, the insulating effect of thermal mass, and, of course, the action of the Sun.

Depending on the building type, the internal heat sources can be either a major or a minor load. Internally dominated buildings have a large amount of heat generated by people, lights, and appliances. The heat can be in both sensible and latent (water vapor) form. Thermal mass can reduce the heat gain when temperatures are fluctuating widely during the day. The insulating effect is most pronounced when the daily temperature range varies from above to below the comfort zone, a situation found in hot and dry climates. Infiltration is generally less of a problem in the summer than in the winter because of the lower wind velocities. Instead, ventilation is often a significant source of heat gain. This is especially true in humid climates because of the sizeable latent-heat component of the air. The same heat recovery devices mentioned above for reducing heat loss can also reduce both sensible and latent heat gain when ventilation brings in hot, humid summer air. Ventilation and heat-recovery devices are explained more fully in Section 16.18. The heat gain due to the temperature difference across a window is calculated the same way as heat loss in winter. Of course, summer indoor and outdoor design temperatures are used.

However, the heat gain due to solar radiation through the glazing is calculated as shown inside box 15.3A. The heat gain calculation through the opaque parts of the thermal envelope (walls, roof, and doors) is similar to that for heat loss except for the extra impact of the Sun heating the outdoor surfaces. The darker the color, the greater the heat gain because dark colors absorb a large amount of solar radiation and get quite hot. This results in a higher temperature differential between indoors and outdoors than can be accounted for by the actual outdoor-air temperature. This larger temperature differential is called the sol-air temperature. When the insulating effect of thermal mass is also included, the temperature differential used is called the design-equivalent temperature difference.

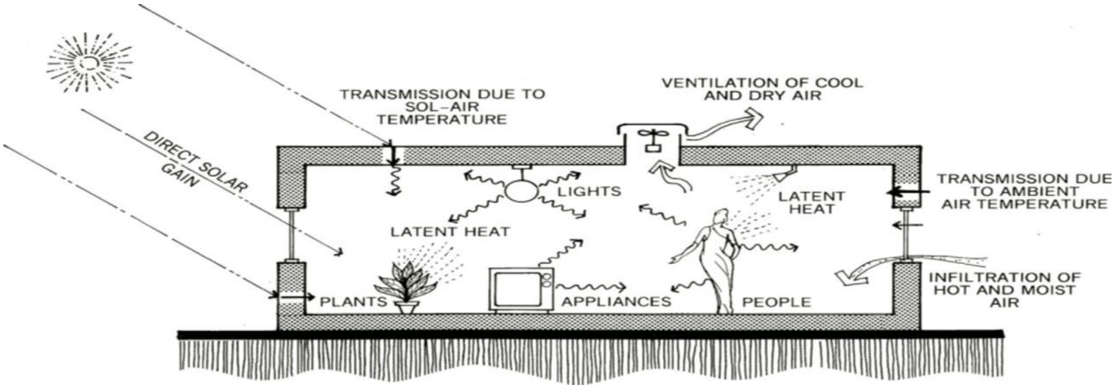

TRANSMISSION DUE TO SOL-AIR TEMPERATURE
VENTILATION OF COOL AND DRY AIR
DIRECT SOLAR GAIN
LIGHTS
LATENT HEAT
LATENT HEAT
TRANSMISSION DUE TO AMBIENT AIR TEMPERATURE
INFILTRATION OF HOT AND MOIST AIR
PLANTS
APPLIANCES
PEOPLE

Figure6: transmission of Heat (WILEY & SONS, 2015)

Side box illustrates how to calculate heat gain through the opaque parts of the building envelope. Since sol-air temperatures are much lower with light-colored surfaces than dark-colored surfaces, one of the most effective and least expensive ways to reduce heat gain is to specify light-colored building finishes. (WILEY & SONS, 2015)

2.3.1.3 Heat Gain through windows:

Windows with both good looks and desired controls for heat flow requires a thorough understanding of how glass responds to solar heat gain, and after that, measures need to be taken to control that heat transfer. Normal clear glass is almost transparent to high-frequency solar radiation but is a barrier to low frequency or longwave radiation. The solar heat energy passing through the glazing warms up the various internal surfaces by absorption, and these internal surfaces then become heat radiators of low frequency reemitted heat, which is trapped inside, causing the temperatures to rise. (ASHRAE, PH.D.John L., Alex McGowan, B.A.Sc, & P.Eng. Member ASHRAE)

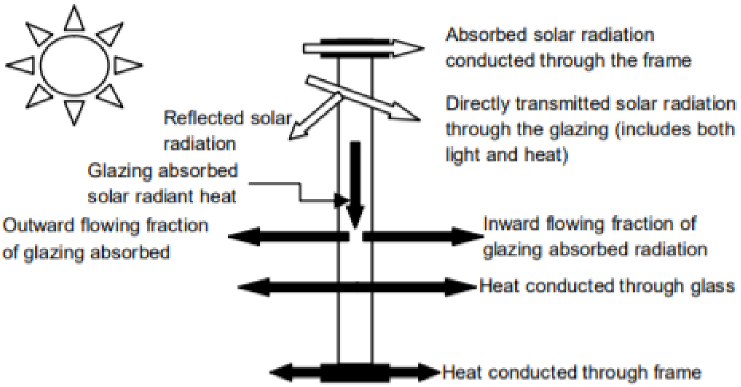

Absorbed solar radiation conducted through the frame
Directly transmitted solar radiation through the glazing (includes both light and heat)
Reflected solar radiation
Glazing absorbed solar radiant heat
Outward flowing fraction of glazing absorbed
Inward flowing fraction of glazing absorbed radiation
Heat conducted through glass
Heat conducted through frame

Figure7: Basics of heat transfer through windows

2.3.1.4 Calculating the Solar Heat Gain of Window Frames

It is not practical to measure the solar heat gain of a window frame. It is more practical to do so by calculation. Typically, the frame solar heat gain is a small component of the total or is small in absolute terms, so an approximate method is satisfactory. A simple approach for calculating the solar heat gain coefficient of any opaque window component is developed. The parameters appearing in the expression identify the mechanisms of frame solar gain and indicate how it can be controlled. A straightforward expression can be applied to any frame geometry for cases where the solar radiation is typical to the window. This is especially useful because this condition is frequently used for energy rating purposes, code compliance, and design. It is shown that this expression is also valid for off-normal incidence as long as no part of the frame is shaded. An adjustment based only on frame surface geometry can be applied if the frame is partially shaded. Sample calculations closely reproduce the results of detailed two-dimensional numerical simulation. (ASHRAE, PH.D.John L., Alex McGowan, B.A.Sc, & P.Eng. Member ASHRAE)

2.3.1.5 Absorbed solar radiation and inward-flowing fraction

Solar radiation incident on the view area of a window is either reflected, transmitted, or absorbed within one of the glazing layers.

It is customarily assumed that all of the transmitted radiation is absorbed at indoor surfaces. A portion of the radiation absorbed in anyone glazing layer will be redirected to either the outdoor or indoor site utilizing heat transfer. The solar gain consists of the energy transmitted directly to the conditioned space plus the portion of the energy absorbed in the glazing layers that makes its way to the indoor side.

A solar optical calculation is used to determine the amounts transmitted and absorbed.

A heat-transfer calculation is used to determine the inward-flowing fraction of the solar radiation absorbed in the glazing layers. (ASHRAE, PH.D.John L., Alex McGowan, B.A.Sc, & P.Eng. Member ASHRAE)

Window frames do not transmit solar radiation, so the determination of frame solar heat gain requires only considering the absorbed/redirected component.

The calculations to determine inward-flowing fraction differ between frames and glazing systems primarily because glazing systems are analyzed using a one-dimensional ~1D! Model and frames using a 2D model. Nonetheless, it is useful to review the glazing-system model's detail because the concepts and approach can be carried over to the frame analysis. (ASHRAE, PH.D.John L., Alex McGowan, B.A.Sc, & P.Eng. Member ASHRAE)

2.3.1.6 Inward-Flowing Fraction for Double Glazing Systems

An optical calculation has been completed giving the absorbed fluxes of solar energy in the conditioned space, S1, and at the glazing layers, S2 and S3. Each glazing layer is assumed to be isothermal, and the heat-transfer analysis has provided the values of thermal resistance, R1, R2, R3, step-by-step through the glazing-system array. Accordingly, the heat flux between each pair of temperature nodes in the array, including heat transfer by convection and radiant exchange, can be written as:

$$q_1 = \frac{T_2 - T_1}{AR_1}, \tag{1}$$

$$q_2 = \frac{T_3 - T_2}{AR_2}, \tag{2}$$

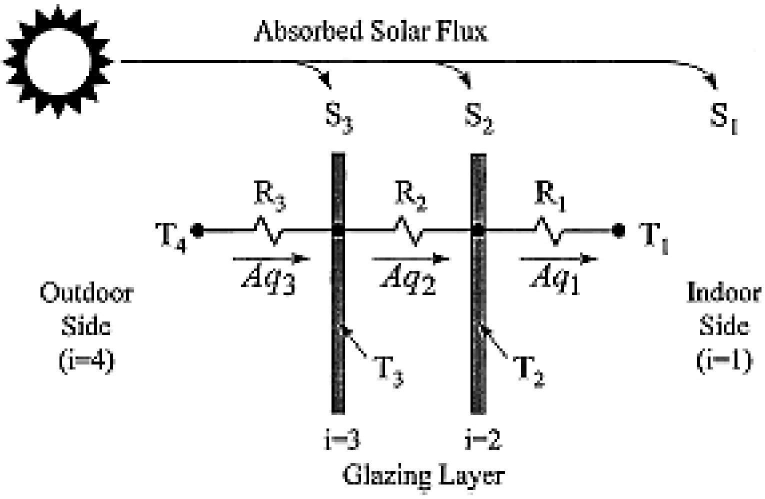


Figure8: resistance network for a double-pane-glazing system (ASHRAE, PH.D.John L., Alex McGowan, B.A.Sc, & P.Eng. Member ASHRAE)

2.3.1.7 ESTIMATING THE SOLAR GAIN OF WINDOW FRAMES

The solar gain of window frames and other opaque window components such as dividers can be estimated like the technique used for glazing systems.

Figure 9 shows the cross-section of a window frame and some of the associated nomenclature. It is assumed that there is little net heat transfer between the frame and the glazing unit or between the frame and the wall. It is also assumed that the frame's surface area exposed to the outdoor environment is isothermal at some temperature Ts. These simplifications allow the thermal resistance network to be drawn as shown in Figure 9. (ASHRAE, PH.D.John L., Alex McGowan, B.A.Sc, & P.Eng. Member ASHRAE)

The frame's thermal resistance consists of three resistances in series, Rout, Rc, and Rin, corresponding to ~1! the outdoor film coefficient, ~2! heat transfer within the frame, and ~3! the indoor film coefficient, respectively.

Each resistance includes the effects of all modes of heat transfer. Thus, in the absence of solar radiation, the heat transfer rate through the frame, Qfr, is given by and Ufer is the frame U factor based on the frame's projected area, Apr ~ASHRAE 1997!. It is also assumed that solar radiation is absorbed only on the outdoor surface of the frame. This source of solar energy on As is not important because the

outdoor surface is assumed isothermal. It is only necessary to know the rate at which solar radiation is absorbed. This absorbed solar energy source is denoted As Ss to emphasize that it consists of some absorbed flux over area. The frame solar heat gain can be determined using an approach similar to the method used to examine glazing systems. (ASHRAE, PH.D.John L., Alex McGowan, B.A.Sc, & P.Eng. Member ASHRAE)

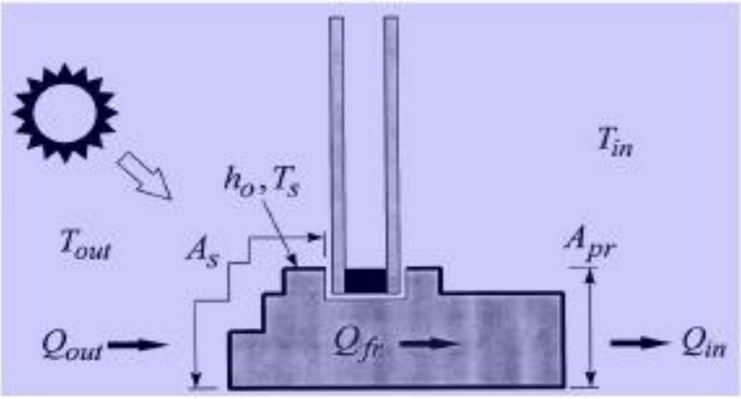


Figure9: cross-section of a window frame

$$Q_{\mathrm{fr}}=\frac{T_{\mathrm{out}}-T_{\mathrm{in}}}{R_{\mathrm{fr}}}=U_{\mathrm{fr}}A_{\mathrm{pr}}(T_{\mathrm{out}}-T_{\mathrm{in}}),$$

where

$$R_{\mathrm{fr}}=R_{\mathrm{out}}+R_c+R_{\mathrm{in}}$$

The following three equations, consisting of two heat-transfer rate equations and one energy balance, are considered:

$$Q_{\mathrm{in}}=Q_{\mathrm{fr}}=\frac{T_s-T_{\mathrm{in}}}{R_c+R_{\mathrm{in}}},$$

$$Q_{\mathrm{out}}=\frac{T_{\mathrm{out}}-T_s}{R_{\mathrm{out}}},$$

$$Q_{\mathrm{out}}=Q_{\mathrm{fr}}-A_sS_s=Q_{\mathrm{in}}-A_sS_s.$$

2.4 Window design in hot climate:

2.4.1 Introduction

Low energy buildings should satisfy two main criteria: they should ensure low energy consumption and provide excellent residential comfort. The building envelope elements exert a significant influence on both tasks. The influence of the transparent parts of a building's envelope is often in opposition to these primary goals despite the technological progress seen in recent years, primarily through low-emissivity layers and multi-cavity windows, the development of windows space, and the use of transparent insulation materials. Some benefits are also provided through integrated shading systems, integrated P.V. modules, and elements used to lead daylight into rooms. Unfortunately, these new technologies are often expensive and inappropriate for the renovation of buildings.

As a method that requires no energy consumption, natural ventilation can significantly improve energy efficiency and indoor air quality. Natural ventilation is suitable for cold and warm climates during the hot and transition seasons and throughout the year in hot climates. Depending on the speed and high-frequency fluctuation of wind, natural ventilation has the potential to meet both the psychological and physiological needs of building occupants. Therefore, natural ventilation should be the preferred air exchanging approach for buildings.

The window size and orientation have to be chosen according to the climate and wind direction. In hot and humid regions, the window-floor ratio is recommended to be 15–20%. Windows are the primary source of heat gain and need to be adequately insulated and covered in order to lower the U-value and to prevent solar radiation from entering.

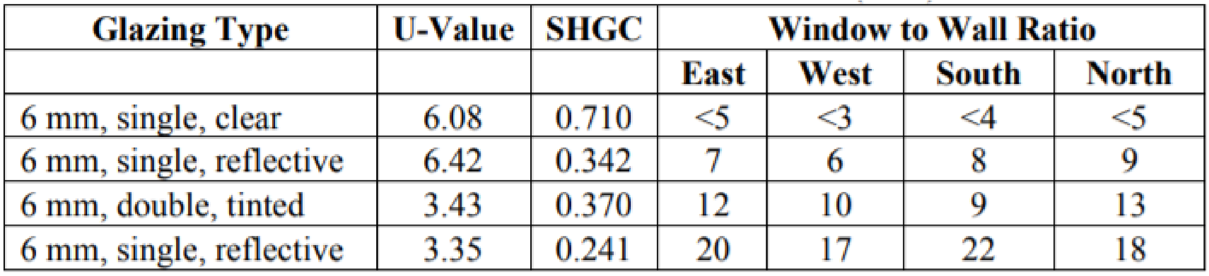
Also, windows have to make sure that sufficient daylight is available for the inhabitants. Different heat gain effects can occur in a window, which has to be considered, including radiation, conduction, convection, and infiltration. The latest widely used technologies on the market are low–emissivity, spectrally selective, tinted heat absorbing, and gas-filled windows combined to create optimum results.

Low-e glasses have a metal or metallic oxide coating to increase their reflectance, decreasing the absorbance and lowering the U-value. According to the U.S. Department of Energy, Low-E glasses cost about 10–15% more in the USA but reduce energy consumption by 30–50% compared to regular windows. However, this can cause a reduced daylight coefficient if spectrally selective coatings are not used. There are two manufacturing technologies to produce low-e class, which results in either hard-coated glass CVD (Chemical Vapor Deposition), also known as pyrolytic, or soft-coated glass MSVD (Magnetron Sputtering Vacuum Deposition), known as sputtered. The soft-coated glass is less durable than hard-coated and requires special storage and handling. (K.Sudhakar, MaximilianWinderldS, & ShanmugaPriyae, March 2019)

2.4.2 Window design in Saudi Arabia:

Investigated air-conditioned spaces in Saudi Arabia then highlights maximum allowable window to wall ratio (in %). Direction-wise for different glazing types based on U-value and SHGC (solar heat gain coefficient). (Al-Shaalan, October 16, 2012)

Table 6 Allowable window to wall ratio



Glazing Type	U-Value	SHGC	Window to Wall Ratio			
			East	West	South	North
6 mm, single, clear	6.08	0.710	<5	<3	<4	<5
6 mm, single, reflective	6.42	0.342	7	6	8	9
6 mm, double, tinted	3.43	0.370	12	10	9	13
6 mm, single, reflective	3.35	0.241	20	17	22	18

2.4.3 Windows shading:

Shading systems are designed to deal with solar radiation. Protection of the building's apertures is the first consideration in the design of shading systems. When designed well, they may also protect the opaque surfaces, including the roof.

Shading systems can help save energy by reducing:

- cooling loads in summer/heat loads in winter
- needed artificial lightning (redistribute daylight).

Depending on the amount and location of fenestration, reductions in annual cooling energy consumption of 5% to 15% have been reported. Shading systems can also improve user visual comfort by controlling glare and reducing contrast ratios.

While the cooling load maybe reduce by shading, any associated reduction of lighting in the space may lead to a higher artificial lighting load. Therefore, shading systems should consider concurrently heat rejection in summer/heat capture in winter, daylighting, and ventilation needs.

2.4.3.1 Solar radiation:

At an average distance of 150 million kilometers from the Sun, the outer atmosphere of Earth receives. Approximately 1367 W/m² of insolation. This varies by around ±2% due to fluctuations in emissions From the Sun itself and by ±3.5% due to seasonal variations in distance and solar altitude .The radiation from the Sun is spread over a wide frequency range. The total energy received from the Sun is divided ca. 50/50 visible/invisible range.

As Figure 10 shows:

•46%_47% represents visible range with a wavelength of 350nm to 780nm

•45% is in the near-infrared range of 780nm to 5000nm

• 8%–9% is ultraviolet radiation.

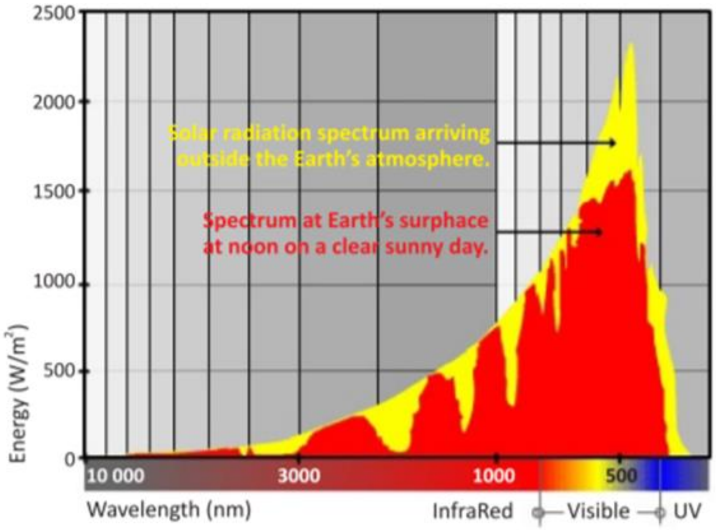


Figure10: spectral content of incident solar radiation

As solar radiation passes through the Earth's atmosphere, some of it is absorbed and scattered (25%) by air molecules, small airborne particles, water vapor, aerosols, and clouds, while the rest arrives somewhere on the Earth's surface. It just happens that most of the particles in the atmosphere responsible for scattering are around 500nm in size. As radiation with longer wavelengths simply ignores these particles, shorter wavelength radiation tends to be scattered more. This makes the sky appear blue — as longer wavelength red and yellow light pass almost directly through while blue light is bounced about all over the place. Near the surface, solar radiation can be divided into:

- direct solar radiation that passes directly through to the Earth's surface. Even in a relatively cold climate, direct solar radiation can be a source of extreme local discomfort, equivalent to a 1000W electric bar radiator for every square meter of exposed window
- diffuse radiation is the radiation that has been scattered out of the direct beam. It is the scattered component that makes the sky look bright and provides the ambient diffuse daylighting
- reflected radiation, which depends on the nature of the actual surface — fresh snow can reflect up to 95% while desert sands reflect 35–45%, grasslands 15–25%, and dense forest vegetation 5–10%. (Uspenskiy, 2013)

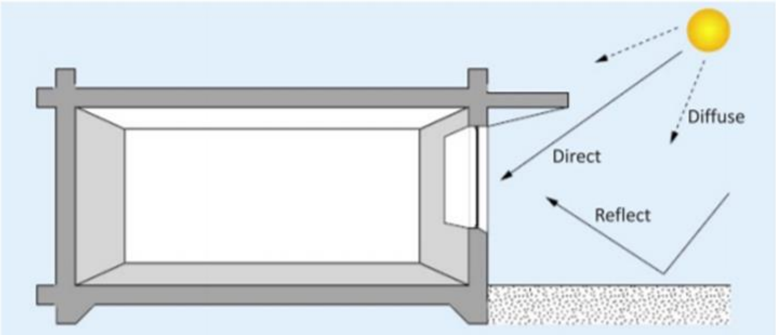


Figure11: components of solar radiation

2.4.3.2 Types of shading systems

Shading systems may be designed to protect transparent and opaque surfaces, which means that shading the building facades and roof can also reduce unwanted heat build-up, particularly when these elements are not insulated and conduction heat flows through the façade into the building. Shading systems can be:

- fixed — cannot change over a day to account for the movement of the Sun.

• adjustable/retractable — operated by occupants or automation. They respond better to the movement of the Sun and allow better control of diffuse radiation. (Uspenskiy, 2013)

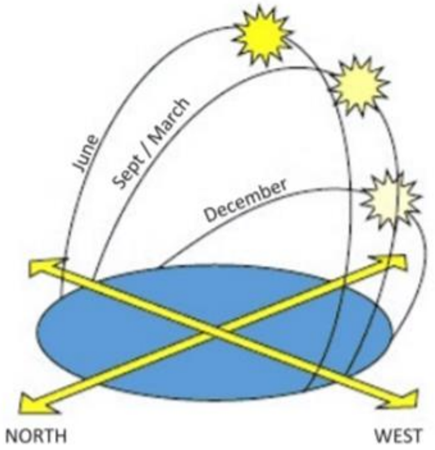


Figure12: summer, winter, equinox sun path

2.4.3.3 Solar control and shading

• overshadowing from: — vegetation (trees‹ vines‹ shrubs) — urban morphology (shading by neighboring buildings) — exterior elements such as overhangs or vertical fins

• combined daylight & shading devices‹ that perform double role of protection against solar radiation and redistribution of light (examples: light shelves‹ Venetian blinds)

• advanced glazing systems (AGS)‹ e.g., tinted/reflective/" low-e"/responsive glass, etc. In many cases, the use of such glasses can save significant amounts of energy. However, if specified or misused, they can add to the heat loads in a building

• Other shading technologies (e.g., transparent insulation materials (Aerogel)). (Uspenskiy, 2013)

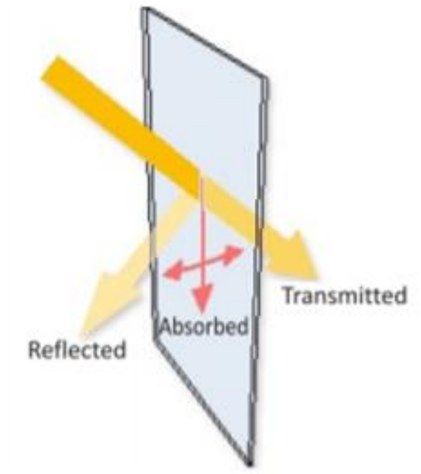


Figure13: the three major components of sunlight

When sunlight hits a pane of glass, it is split into three major components: reflected, absorbed, and transmitted through. The reflected and transmitted components remain as visible and short-wave infrared wavelengths. The energy from the absorbed component heats the pane of glass and is radiated back out into the environment as heat (long-wave radiation). Using a highly reflective glazing makes the reflected solar radiation someone else's problem in an urban environment. With specified restrictions on reflectivity, all that is left for manufacturers is to increase the absorbed component. Thus, a plethora of tinted and spectrally selective glazing available. Such glasses do work — in that they reduce the transmission of direct solar radiation — however, if misused, you will end up gaining almost as much heat by long-wave radiation as you would have by short-wave if you had used regular glass. Tinted windows, for example, can become very warm (up to 50°C). Some of this heat is then radiated to the interior space, causing discomfort to anyone nearby. (Uspenskiy, 2013)

2.4.3.4 Position of shading devices

Shading devices may be located at the:

- internal face of the façade, or
- within double- and triple-glazed windows.

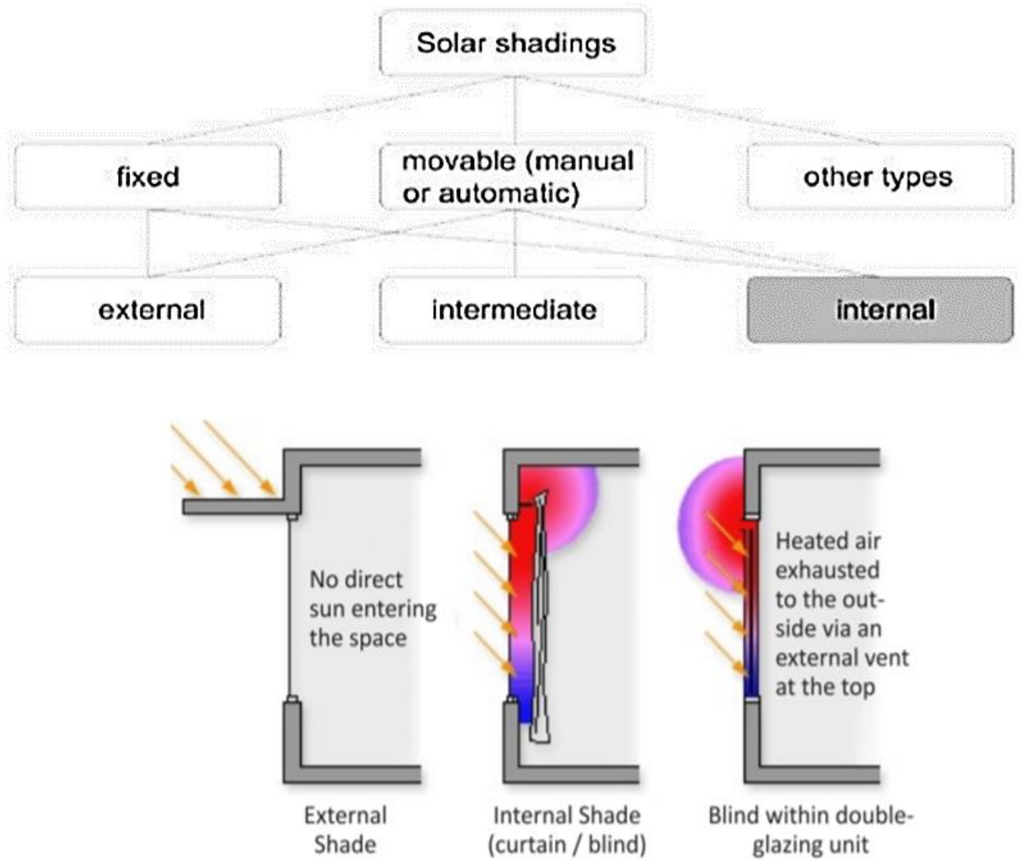

Solar shadings
fixed
movable (manual or automatic)
other types
external
intermediate
internal
No direct sun entering the space
Heated air exhausted to the out-side via an external vent at the top
External Shade
Internal Shade (curtain / blind)
Blind within double-glazing unit

Figure14: location of shading devices

External shading devices are particularly effective against direct solar radiation. Due to their wider angles of incidence, the diffuse and reflected components are more difficult to control and are thus more effectively controlled by internal or mid-pane devices. External shades intercept and dissipate (by convection) most (up to 95%) of the direct radiation before reaching the building façade. As a result, solar heat gain is prevented from passing into the building, minimizing ventilation requirements, and reducing cooling loads. If a controllable system is installed, adjustable louvers track the Sun's position, thereby optimizing the avoidance of overheating. Equally, in winter, the louvers may be adjusted so that the building benefits from the Sun's heat, and they can be closed at night, reducing heat loss.

Similarly, daylight levels can be enhanced, and levels of glare reduced. Where possible, you should always use external shading devices. In internal shading devices, the solar radiation passes through the glass and hits the shade, effectively heating it. Thus, the effectiveness of most internal shades in preventing heat gain to the internal space is limited. Internal devices protect occupants against the immediate effects of direct sunlight and glare, but most of the heat absorbed is released into the room by convection (traditional interior blinds or drapes). Internal devices with a reflective external coating reduce this effect by reflecting some of the outside's transmitted radiation. When using internal shades, installing a sealed pelmet to prevent vertical circulation of air is advisable. In Tas, only one temperature per zone is calculated. To understand the various phenomena that occur in the double-skin, we subdivided this one into several zones. Separations are fictitious walls that can be completely open. The factitious walls have minimal thermal resistance and a solar transmission of 1. Vertically and horizontally, subdivisions are possible. The horizontal subdivisions are tracked floors. The Track label has a unique function that allows the floor to be modeled as an airflow aperture. The solar radiation that strikes the tracked floor is not stopped by the floor and enters the adjacent zone. A permanently open window models the vertical subdivisions. (Gratia & AndréDe Herde, 2006)

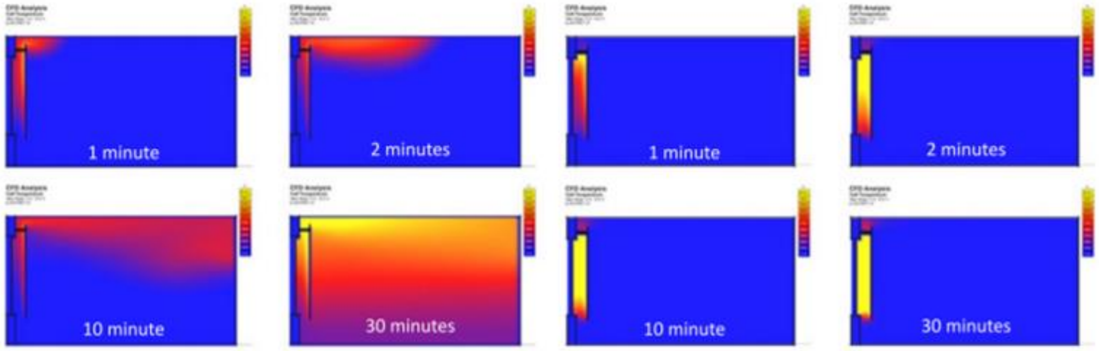


Figure15: propagation of hot air without sealed pelmet and with it.

When accompanied by adequate ventilation to the outside, mid-pane devices combine the advantages of external and internal shades. Heat gains are dissipated to the outside, but the shades are protected from the severity of the outdoor climate. Mid-pane devices are particularly useful in controlling glare.

2.4.4 Windows blinds:

2.4.4.1 Understanding Different Window Treatments:

More often than not, the term 'blinds' refers to both blinds and shades. While all different blinds and shades serve the same primary function, there is a fundamental difference that separates the two. So, before we go any further, let us make sure we understand what makes them different.

2.4.4.2 Types of window blinds:

2.4.4.2.1 Vertical Blinds

Vertical blinds have individual slats that run along a track at the top of the blind. Depending on the style, vertical blinds either open from side to side or by parting in the middle. These blinds are a popular choice for patio doors and floor to ceiling windows. Nevertheless, they can still be used over smaller windows as well. (stratosphere)

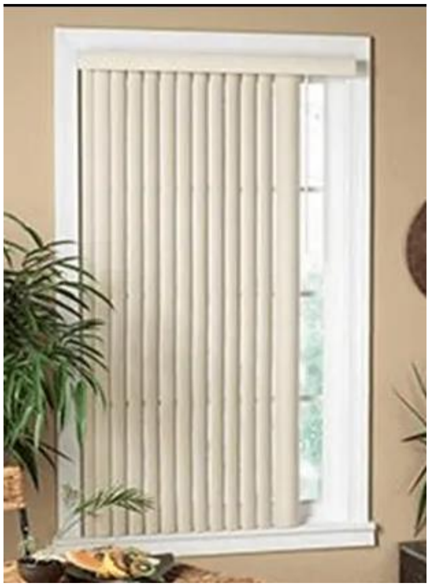


Figure16: Vertical Blinds

2.4.4.2.2 Venetian Blinds

Venetian blinds are the most popular style of blinds. They feature horizontal slats which attach with string or strips of cloth known as tapes. As Venetian blinds are raised, the bottom slat is pressed into the slat above it. (stratosphere)

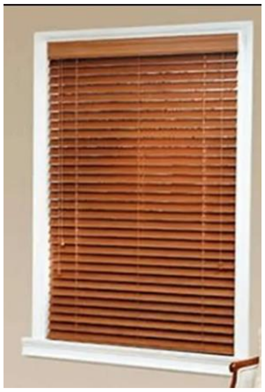


Figure17: Venetian Blinds

2.4.4.2.3 Mini Blinds

Mini blinds are very similar in operation to Venetian blinds. Nevertheless, they feature slats of a smaller width than traditional Venetian blinds. The slats are usually about 1" thick. (stratosphere)

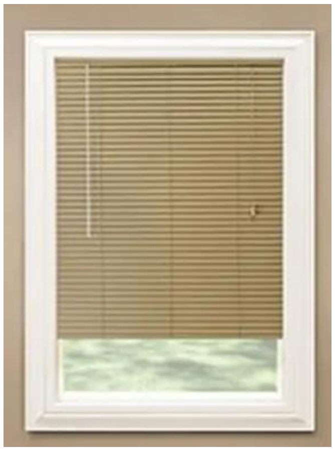


Figure18: Mini blinds

2.4.4.2.4 Micro Blinds

Micro blinds are an even tinier version of mini blinds. These types of blinds feature slats that are ½" thick. (stratosphere)

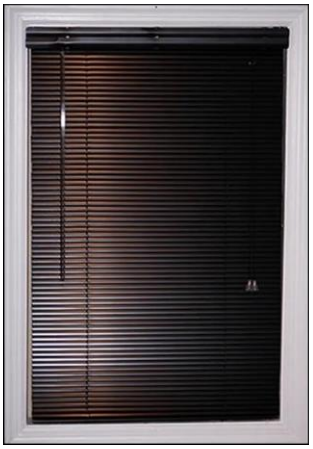


Figure19: Micro blinds

2.4.4.2.5 Panel Blinds

Panel blinds are another popular choice for patio doors, as well as huge windows. Panel blinds feature sections that move along a track, which allows to open and close them. (stratosphere)

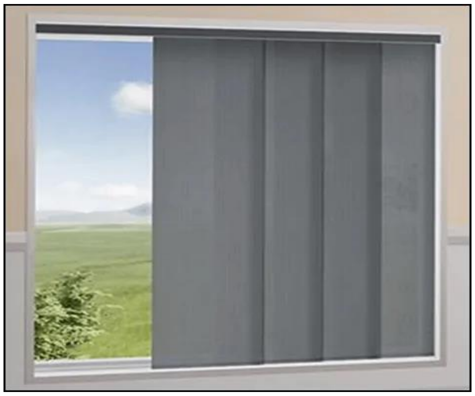


Figure 20 Panel blinds

2.4.4.2.6 Pleated Shades

Pleated shades feature a piece of material that is pleated so that the shade forms an accordion-like pattern which can be raised or lowered. These shades have a similar look to Venetian blinds while also "softening" the window's look. However, they cannot be adjusted from side to side, like blinds. Pleated shades are usually made from fabric or paper. (stratosphere)

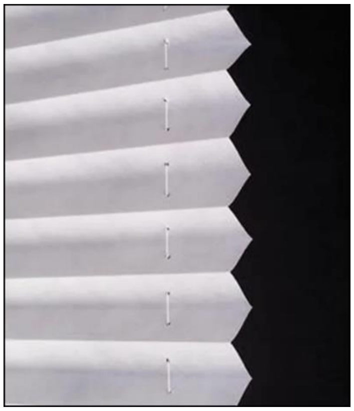


Figure 21 Pleated shades

2.4.4.2.7 Cellular Shades

Cellular shades look similar to pleated shades and are also made from similar materials. However, unlike a pleated shade, cellular shades are made of two different pieces of material. The front and back sections of cellular shades are open in the middle, which creates a pocket that provides insulation. Cellular shades are available in various cell sizes designed to fit the needs of different windows. These shades are a great way to help the home stay cool in the summer and warm in the winter. Cellular shades also provide sound insulation, as well. (stratosphere)

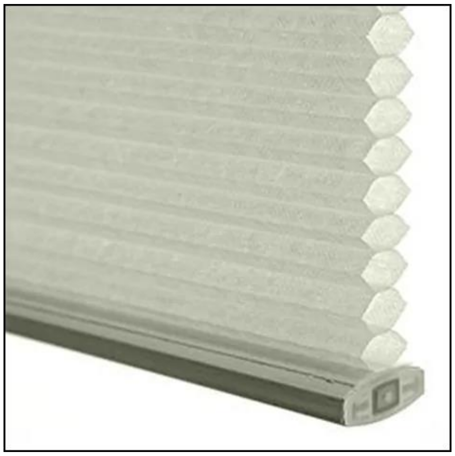


Figure 22 Cellular shades

2.4.4.2.8 Roman Shades

Roman shades are a very traditional window covering made from fabric or materials like jute or seagrass. There are several different styles of Roman shades available, but they all share one thing in common: As a Roman shade is raised, it folds into itself, similar to how a Venetian blind operates. Since the fabric of a roman shade continues to fold into itself, it can create quite a large stack of fabric at the top of the window when they are raised entirely. So, while Roman shades offer a beautiful and timeless look, they remove a portion of the window's viewable space when raised. Roman shades are available both lined or unlined to suit different needs. The linings often offer additional features, like blackout and thermal linings. (stratosphere)

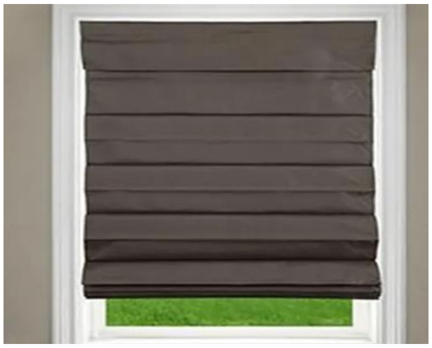


Figure 23 Roman shades

2.4.4.2.9 Roller Shades

Another popular shade option is roller shades. Roller shades are usually made from synthetic or natural fabrics and can be rolled up or down to suit our needs.

Roller shades are available in several different styles that mount to the window in various ways. The most economical roller shades feature an external system that allows us to see all of the different mechanisms and mounting hardware of the shade.

More stylish options are available, including valances, cornices, or fascia, which hide all of the shade's components and provide a more polished look. Like Roman shades, roller shades are available in a broad range of natural and synthetic fabrics and often have additional features such as thermal or blackout linings. (stratosphere)

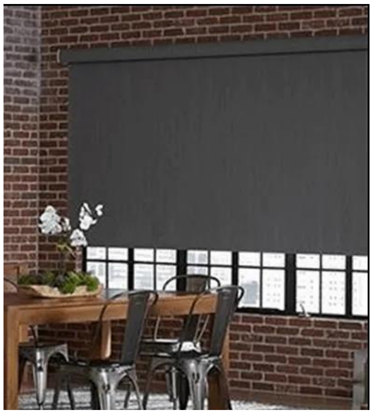


Figure 24 roller shades

2.4.4.2.10 Tie-Up Shades

Tie-up shades are sort of like a cross between a shade and a curtain. Tie-Up shades are available in a broad range of materials. These shades are constructed from a fabric piece that features ties that extend beyond the bottom of the shade. You can raise the shade by rolling it up and then tying the shade in place. This style of shade offers a casual or country look that blends seamlessly with many styles of decor. (stratosphere)

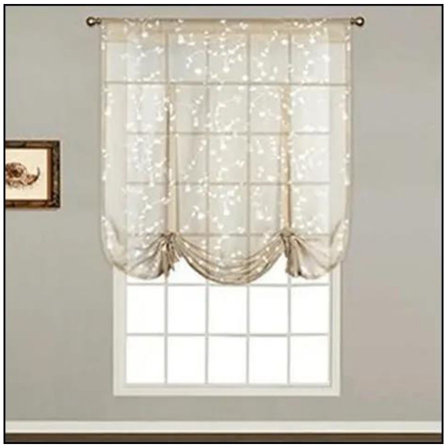


Figure 25 Tie-up shade

2.4.4.2.11 Solar Shades

Solar shades are very similar to roller shades. Their purpose of reducing the amount of sunlight, glare, U.V. rays, and heat was entering the room from outside while preserving the window's view. Solar shades are like sunglasses for your windows. (stratosphere)

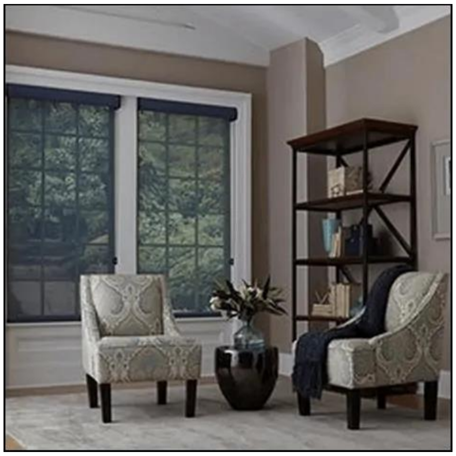


Figure 26 Solar shades

2.4.4.2.12 Outdoor Shades

Outdoor shades are usually made from heavy-duty, weather-resistant materials. Outdoor shades are used on patios and decks to reduce the amount of sun exposure and heat entering the area. Outdoor solar shades are trendy. (stratosphere)

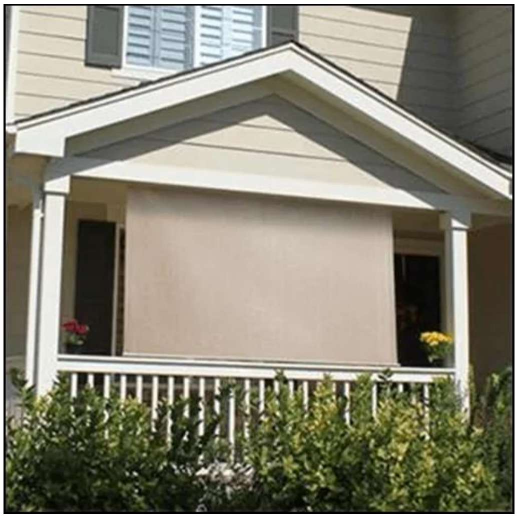


Figure 27 Outdoor shades

2.4.4.2.13 Skylight Shades

Skylight shades are available in many different styles, including roller, pleated, and cellular. These shades are designed to cover challenging to reach skylights. Cellular shades are trendy for skylights because of their insulating properties. Skylight shades usually feature a mostly removable rod used to raise, lower, or adjust the shade. Sometimes, skylight shades are raised or lowered with a handle instead of a rod. Automatic versions are also available. (stratosphere)

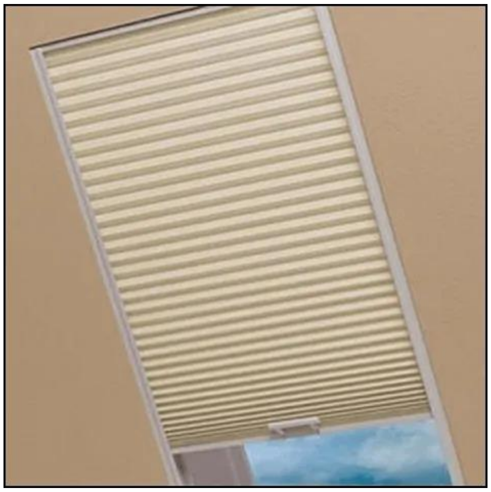


Figure 28 Skylight shades

2.4.4.2.14 Smart Blinds

They still may seem like something out of a science fiction novel, but smart blinds are becoming increasingly common thanks to smart home technology. Smart blinds and shades are available in many traditional styles and new, high tech styles. Smart blinds sync with a smartphone application and can be controlled in groups or individually. They can also be programmed to open and close at specific points during the day. Not only are smart blinds some of the most visually attractive on the market, but they can also help you save on energy costs. If you are interested in smart blinds but do not want to shell out the cash to retrofit your home with them, there are also smart controllers available. These smart controllers allow you to outfit your existing blinds with the same smart technology type that pricey smart blinds use. (stratosphere)

Figure 29 Smart blinds

1.1.1.3 Blinds Materials:

- Wood, Faux Wood, Plastic, Metal, Paper, Natural Fabrics, Synthetic Fabrics.

2.5 Previous studies:

2.5.1 The study carried out by Mamdooh Alwetaishi in his research says:

It is architecturally accepted that the glazing system is considered the most fragile part of indoor energy performance. It is the only part of the building which has direct solar gain due to the transparent materials. Consequently, this part of the building envelope should reap high consideration by architects and engineers, particularly in regions where solar radiation is high. The research investigates the influence of glazing to wall ratio in different microclimate regions in Saudi Arabia, introduced by the author in hot, dry, hot, humid, and moderate climates. The research has studied the possible glazing ratio in the region based on previous work 5%, 10%, 20%, 30%, and 40% out of the external wall. The paper used computer modeling TAS EDSL which has been validated using field monitoring study.

Moreover, a globe thermometer is used to investigate the impact of a student's position concerning the glazing system. Finally, a questionnaire will be utilized to obtain actual thermal comfort from students in the selected regions with maintaining the same PSBD. The study reveals that south and east directions are the worst in gaining the maximum amount of heat in all the locations. The research suggests that the glazing to wall ratio is recommended to be 10% in both climate conditions, hot and dry and hot and humid. (Alwetaishi, Impact of glazing to wall ratio in various climatic regions A case study, 2018)

2.5.2 The study carried out by Alaa Mohammed Shatwan in his research says:

Architecture in Jeddah city in the western region of the Kingdom of Saudi Arabia (KSA) has gradually undergone a significant shift in style, a consequence of the implementation of contemporary Western architecture after the oil boom in the country in 1970. Contemporary buildings with letterbox windows have become popular in the area, replacing the traditional appearance of local buildings characterized by the Roshan (a type of window used in vernacular Jeddah architecture). Characteristics of contemporary architecture do not seem to fit the local context. Consequently, modern Muslim women's needs have been disregarded in favor of a new aesthetic in the course of implementing recent changes in technology and architecture. Research on the current trajectory that architecture has recently taken in the country is needed to explore these consequences. In particular, this study focuses on window design, considering openings as a pivotal element between daylight control and cultural, religious, and personal aspects of today's Saudi women. This study aims to examine daylight and window design to accommodate better women's needs in flats in Jeddah built from 1970 to 2016. The window is analyzed in this study as a pivotal element of the transition between vernacular and contemporary architecture in Jeddah, with implications for the interior quality of space in blocks of flats, including wellbeing and daylight conditions and functional and symbolic values. The first part of my data collection is dedicated to survey photography and floor plan drawings for blocks of flats in Jeddah. Primary data are then generated through interviews with women to understand their perceptions about window design and daylight in their living room spaces. The third dataset is based on daylight calculation, which involved computer modeling applied to Jeddah's interviewees' flats. These phases have unearthed an apparent discrepancy between the design principles employed by the decision-makers and the female population's wishes, who use the residential spaces for most of the time.

The former consider the amount of daylight sufficient; the latter perceive their homes to be dark and unhealthy. The fourth part of this study comprises interviews with architecture professionals (professors of architecture, municipality officers, and architects) to determine where this discrepancy originates and to what extent a reconsideration of design tenets or guidelines can resolve the issue. The study concludes by examining the reasons behind the current issues of inadequate daylight and privacy for Saudi women. It revealed that daylight was less than 100 lux in most participants' flats. The levels ranged between 50 lux and 70 lux, which does not meet the Saudi climate's target. This medium harm women's wellbeing and satisfaction. It also reveals that women's needs in home design are not a significant consideration for architects. Also, it shows that the absence of detailed building regulations regarding window design and daylight levels is the primary reason for this issue. The results show a significant difference between the answers from women and the answers from professionals in terms of the small gap between buildings and daylight levels (P=0.005). The results also show a statistical difference between women's and professionals' responses about whether daylight levels or measurements are considered when designing living room windows (P=0.019). In conclusion, this study proposes a set of guidelines to policymakers that building regulations should be updated to consider the findings of this study to provide better new regulations that consider women's needs in flat windows design. (Shatwan)

2.5.3 The study carried out by Tobias Rosencrantz in his research says:

This Licentiate dissertation deals with windows and solar shading devices and how they could be designed and used to save heating and cooling energy in buildings. Parametric studies using the dynamic energy simulation software Parasol v 2.0 were performed for different windows and solar shading devices. One study showed that both the cooling load and the annual cooling demand could be decreased by a factor of two by using external solar shadings. For internal solar shadings, the cooling load and the cooling demand decreased only by one third. The general conclusion of this study is that external shadings are much more efficient than internal shadings. When low-e windows are used, the daylight transmittance decreases compared to clear glass windows. To avoid this effect, a study of anti-reflective coatings on low-e windows was made. Simulations of the annual energy demand were performed in Parasol, and the daylight distribution was studied in Ray front. Ray front is a user interface to the light simulation software Radiance. It was shown that low-e windows with an anti-reflecting coating increase the daylight transmittance to become even higher than a clear glass window. However, the anti-reflective coating did not decrease the heating demand in any significant way. Instead, it was the low-e coating that accounted for the most considerable energy saving. A study of solar-control windows and internal solar shading device measurements were performed in the solar laboratory at Energy and Building Design. The measurements were compared with simulations in Parasol. The results showed that the efficiency of the solar shadings increased with decreasing window absorption. Simulations of an ideally reflecting solar shading proved that internal solar shadings could be useful if they are positively reflecting and used combined with non-absorbing clear glazing.

A recommendation is that the g-value, or solar factor, should be given for the whole system (window plus shading device). If it is given only for the internal solar shading, the g-value of the window it is combined with must also be given. In a study of angle dependency of solar shading, a new model for characterizing the g-values of asymmetric and symmetric shadings was introduced. The new model was verified by outdoor measurements, indoor measurements, and ray-tracing. The model worked well for Venetian blinds, screen, and diffuse film. The awning model had to be modified slightly to account for edge effects for incidence angles larger than zero degrees. (Rosencrantz)

2.5.4 The study carried out by Licentiate in his research says:

Earlier studies in the context of windows and blinds selection have mostly tried to increase the awareness regarding various effects of windows and blinds selection on subjective well-being, including their effect on visual comfort, thermal comfort, energy consumption, and life cycle cost. However, the main problem is the potential conflicts between visual comfort, thermal comfort, energy consumption, and life cycle cost. Increased awareness about the contradictory effect of windows and blinds selection on subjective well-being on the one hand and lack of a feasible method in managing the conflicts, on the other hand, may bind individuals, as decision-makers, in a situation where they follow the immediate economic benefits rather than the long-term visual and thermal benefits .To solve the mentioned problem, this study analyzed first the degree of the conflicts between average daylight illuminance and total energy consumption in Sweden.

This decision was made due to a considerable variation in solar elevation angle and solar intensity between summer and winter in Sweden, which significantly affects daylight illuminance and total energy consumption. Analyzing the conflicts was accomplished by developing two multivariate linear regression models for calculating average daylight illuminance and total energy consumption. Comparison and analysis of the multivariate linear regression models showed a high degree of conflicts, which makes window and blind selection a rather complex multidimensional problem. Specifying the degree of the conflicts formed a hypothesis as: “A multi-criteria decision-making method increases the controllability and manages the conflicts in selecting windows and blinds.” The developed hypothesis was later tested by employing the analytical hierarchy process, as widely used multi criteria decision-making. The analytical hierarchy process prioritizes the decision-maker’s preferences and introduces a desired trade-off solution. The analytical hierarchy process results showed the capability to manage the conflicts among visual comfort, thermal comfort, energy consumption, and life cycle cost. Finally, the application of the analytical hierarchy process was expanded by integrating it with nondominated sorting genetic algorithm-II as an optimization algorithm. Through this integration, the optimization algorithm combines windows’ and blinds’ design variables and analyses many solutions, while the analytical hierarchy process ranks the solutions based on decision-makers’ preferences and introduces a desired trade-off solution. The integration between the analytical hierarchy process and the nondominated sorting genetic algorithm-II was presented later as a conceptual framework. The developed conceptual framework can be used for selecting windows and blinds in both residential and commercial buildings. In selecting windows and blinds, the conceptual framework is a novel solution to the lack of a feasible method for increasing decision-makers' controllability and obtaining a desired trade-off solution. (licentiate)

2.6 Climate condition in Saudi Arabia

Saudi Arabia is situated in the southwest of Asia at the junction of Africa and Asia and is the largest country (occupying 80% of the area) in the Arabian Peninsula (CSD, 2010). The country has mountain ranges in the western region, situated parallel to the Red Sea coast. The Rub Al-Khali is the world’s largest sand desert, covering almost the entire south-eastern region of Saudi Arabia (Atals, 2012). The climate of Saudi Arabia is scorching and dry (Almazroui R. , 2019). As studied by (Almazroui A. a., n.d.), the rainfall climatology is such that the country receives large amounts of rainfall in the northern, central-northern, and southwestern regions, whereas the south-eastern region is almost entirely dry. The south-western region of Saudi Arabia receives rainfall in almost all months of the year, whereas the northern region receives most of its rainfall during the winter and spring seasons (Almazroui A. a., n.d.). In the northern region of the country, the climate parameters are associated with westerly disturbances, the Sudan trough, and the Mediterranean region's storms, whereas the southern climate is influenced by the Indian Ocean monsoon circulation (Sen, 2002).

A few studies have been conducted in the Arabian region to understand the behavior of its temperature climatology: For the whole of the Middle East, (Almazroui A. a., n.d.) for Saudi Arabia, (Almazroui A. a., n.d.) for Kuwait (Almazroui A. a., n.d.) and Jordan (Almazroui A. a., n.d.). However, most of these studies mainly addressed the temperature trends and their relationship with water resource management. Furthermore, these studies used the available surface observation data, which are very sparse in this region. Of further significance is the fact that ENSO, NAO, and AO are also significant drivers of the climate of the northern hemisphere, as discussed in several studies, and it is therefore of vital importance to examine the effects of these external forces (NAO and AO) on the region's climate. However, in the past, very little research has been conducted to address the relationship between the temperature and the large-scale forcing in the study region. For example, (Circulation Weather types as a tool in atmospheric, climate and environmental research, 2015). studied the mean temperature of only four stations over Saudi Arabia and their relationship with ENSO phenomena. Unfortunately, no attempt has been made to detect the impact of NAO and AO on the seasonal temperatures of Saudi Arabia. This work is thus the first attempt at investigating the effects of these large-scale forcing on the temperature over Saudi Arabia. Specifically, the current study investigates the relationship between the mean temperatures in Saudi Arabia with the large-scale forcing, using the available observed data (from 27 stations) and the gridded reanalysis datasets. It is envisaged that the research will be useful in understanding how ENSO, AO, and NAO affect the temperature climatology of the study area.

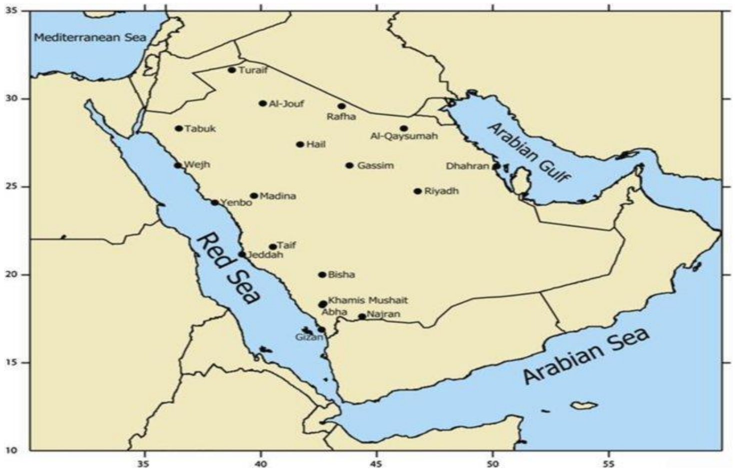


Figure 30 Saudi Arabia.

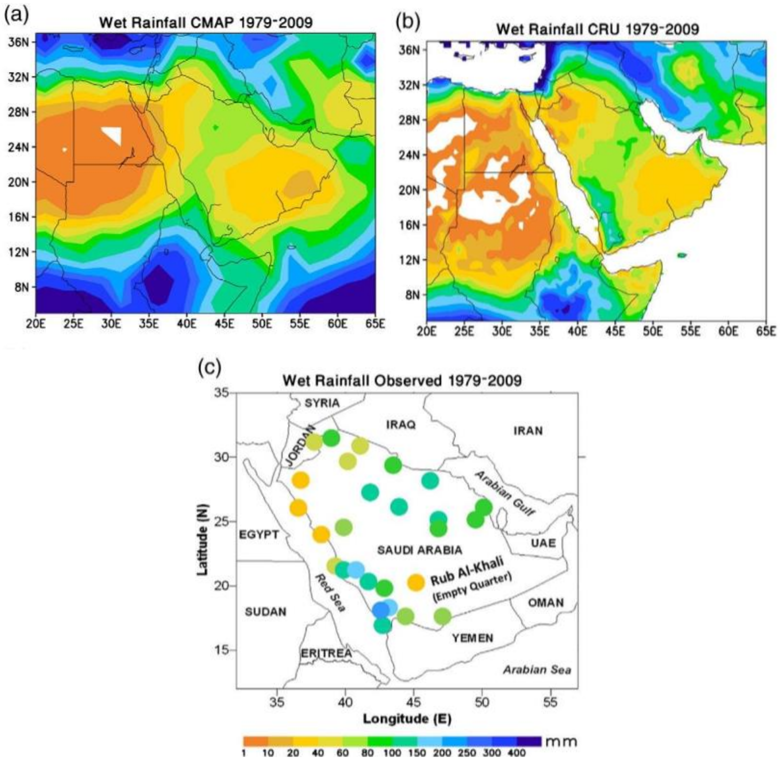


Figure 31 RAINFALL IN SAUDI ARABIA FROM 1979-2009

The climate of KSA is generally hot and dry. A/C plant capacity for a building must be accurately determined to conserve power and energy and provide a comfortable indoor environment. Oversizing leads to higher initial investments and greater energy consumption by auxiliaries such as pumps and fans, while under-sizing results in discomfort.

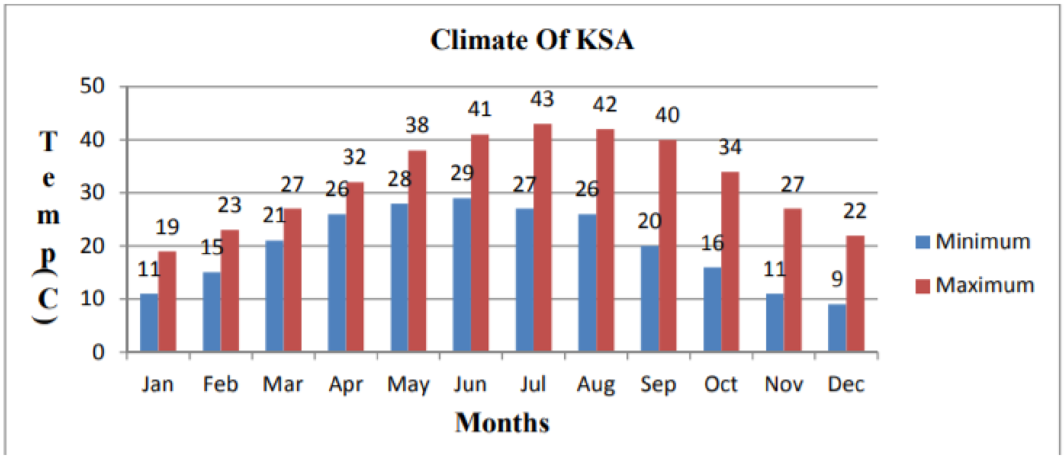


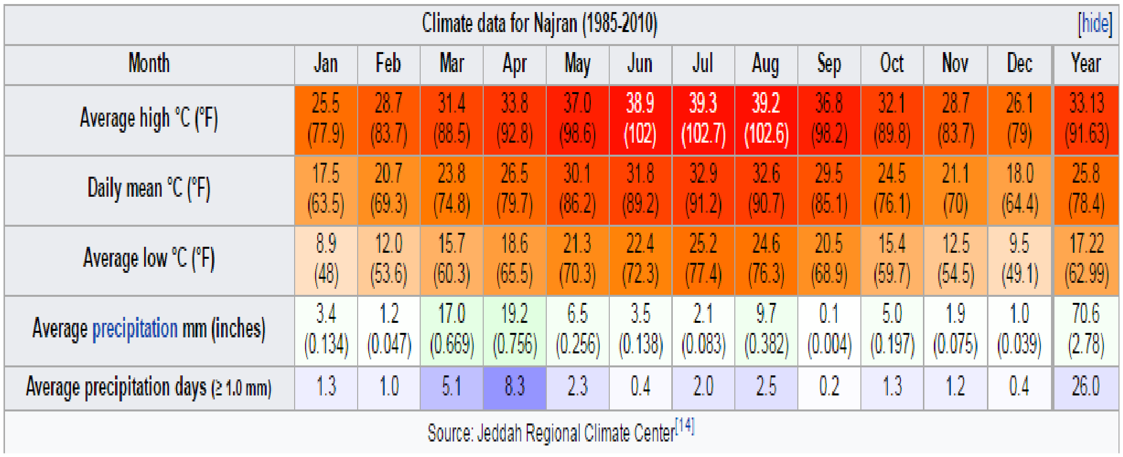
Figure 32 mean temperatures of KSA month-wise

2.6.1 Ambient Climatic Conditions of Najran

The climate of Saudi Arabia is characterized by extreme aridity and heat. During summer, the average temperature ranges from 27–43 °C in inland regions and 27–38 °C in coastal regions. Except for the mountainous regions in the southwest, Saudi Arabia is known for its desert weather and climate. An extreme amount of heat characterizes it during daytime and a sudden drop in temperature during nighttime. Moreover, the country does not receive a large amount of rain. The yearly precipitation is around 100 mm (KRISHNA, 2020).

These factors make Saudi Arabia one of the world's hottest countries with low humidity except in summer along the coastal regions. Therefore, people consume a high amount of energy to create indoor thermal comfort because of the harsh hot–arid climate, cheap energy availability and improved per capita GDP.

The climate for Najran is a hot desert climate type, typical of the Arabian Peninsula. The Rainfall is very sporadic in occurrence and individual light rainfalls. The yearly average high temperatures are lower than that of Riyadh, despite being further south, due to its elevation.



Climate data for Najran (1985-2010) [hide]

Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year
Average high °C (°F)	25.5 (77.9)	28.7 (83.7)	31.4 (88.5)	33.8 (92.8)	37.0 (98.6)	38.9 (102)	39.3 (102.7)	39.2 (102.6)	36.8 (98.2)	32.1 (89.8)	28.7 (83.7)	26.1 (79)	33.13 (91.63)
Daily mean °C (°F)	17.5 (63.5)	20.7 (69.3)	23.8 (74.8)	26.5 (79.7)	30.1 (86.2)	31.8 (89.2)	32.9 (91.2)	32.6 (90.7)	29.5 (85.1)	24.5 (76.1)	21.1 (70)	18.0 (64.4)	25.8 (78.4)
Average low °C (°F)	8.9 (48)	12.0 (53.6)	15.7 (60.3)	18.6 (65.5)	21.3 (70.3)	22.4 (72.3)	25.2 (77.4)	24.6 (76.3)	20.5 (68.9)	15.4 (59.7)	12.5 (54.5)	9.5 (49.1)	17.22 (62.99)
Average precipitation mm (inches)	3.4 (0.134)	1.2 (0.047)	17.0 (0.669)	19.2 (0.756)	6.5 (0.256)	3.5 (0.138)	2.1 (0.083)	9.7 (0.382)	0.1 (0.004)	5.0 (0.197)	1.9 (0.075)	1.0 (0.039)	70.6 (2.78)
Average precipitation days (≥ 1.0 mm)	1.3	1.0	5.1	8.3	2.3	0.4	2.0	2.5	0.2	1.3	1.2	0.4	26.0

Source: Jeddah Regional Climate Center[14]

Figure 33 climate data for Najran

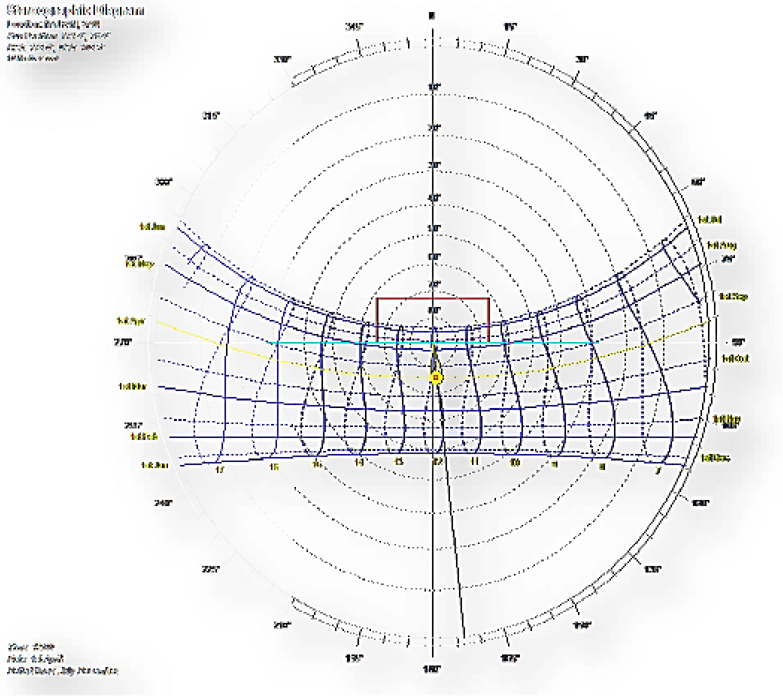


Figure 34. The sun path of Najran city throughout the year

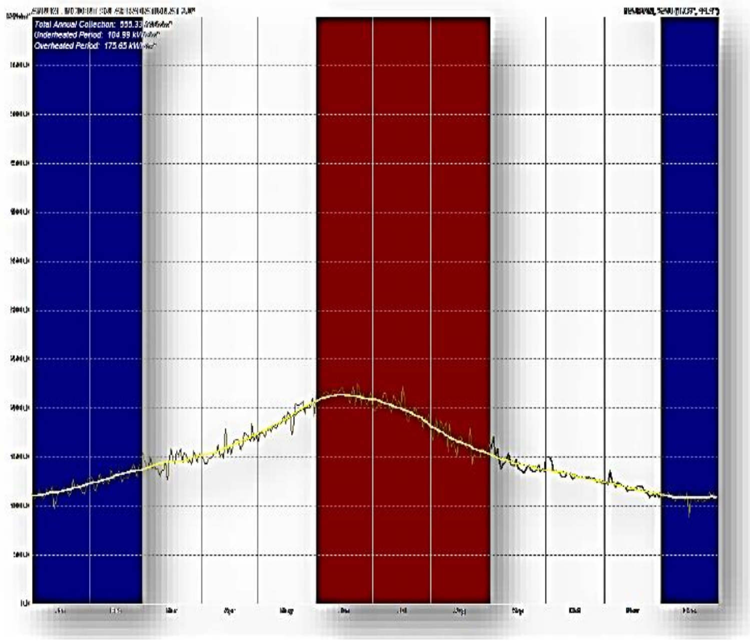


Figure35. The annual level of the solar radiation falling on the city of Najran. by design-Builder

CHAPTER 3
METHODOLOGY

Before starting any research project, it needs to decide what methods to collect data and examine the research hypothesis of the proposed topic. Researchers use three basic types of methodology: qualitative, quantitative, and mixed. More specific methods include a range of options within these broad categories, such as case studies, self-reports, and surveys.

Quantitative research is more objective than qualitative methods. In Quantitative methodology, the researcher crafts a hypothesis and then tests it through structured means. This type of research is often used in science, such as the topic of this project.

3.1 The adapted methodology in this study:

This study adopts the case study was investigated in several previous project (rationing project of ARE in Najran University). The study uses the residential building data and comes direct to build a model in a selected simulation program.

3.2 The Energy Simulation Software Tools

3.2.1 Introduction

The energy simulation software tools can be essential for reducing the cost of energy in buildings. About one-third of the energy consumption in buildings is used to increase the dwellings' thermal conditions and lighting. Thermal simulation software tools for buildings allow to:

- Determine the appropriate size of HVAC systems.
- Analyze the energy consumption.
- Calculate the cost of the energy used.

Nowadays, designers need tools that answer particular questions, even during the initial design phase. Through energy simulation software, designers can consider specific choices (e.g., heating and cooling). Designers can also predict buildings' thermal behavior before their construction and simulate energy costs in existing buildings in their current conditions, establishing the best thermal retrofitting measures to adopt in the buildings under analysis. Besides the energy consumption, simulation software tools can also be used to calculate the following variables: (Sousa1)

- Indoor temperatures.
- Needs for heating and cooling.
- Consumption needs of HVAC systems .
- Natural lighting needs of the occupants.
- Interior comfort of the inhabitants.
- Levels of ventilation.

3.2.2 Energy simulation software for buildings types

3.2.2.1 Design Builder

Design Builder provides a graphical, integrated experience to help predict energy efficiency and occupant comfort in buildings. Design Builder Detailed Heating, Ventilation, and Air-Conditioning (HVAC) system Graphic User Interface (GUI) makes it easy to model thorny, customized HVAC plants, and systems in Energy Plus. (Sousa, n.d.)

The Design Builder program was chosen to run the simulation in this project based on several points:

1- The program is cheaply priced, quite easy compared with other simulation programs.

2 - The accuracy of the results shown by the program.

3 - Provides all the needs that we want to investigate.

4- Many researchers used this program in their research.

Variables that used in this study and simulated in the Design Builder program are as in table7.

Table 7: The investigated variables.

Independent variable	**EXPERIMENTS**	***Dependent variable*:**			***Reduction***
		Cooling energy	***Lighting energy***	**Energy Per Total Building Area [kWh/m2]**	
Clear single glass	6% glazing-BC				
	10% glazing				
	15% glazing				
	20% glazing				
Double low-e-clr	20% glazing				
outside	**Venetian**				
	Roll				
Mid-pane	**Venetian**				
	Venetian-air flow				
Inside	**Venetian**				
	Roll				
Electrochromic Switchable	**Switchable**				

CHAPTER 4

Selecting a building and surveying a Tenant’s preferences

4.1 Introduction:

This chapter concerns on the residential buildings that will be investigated and simulated. First, the study has gone through a selected villa getting the detailed drawings from the project manager. This drawings and details will be used for building a simulated model. Second, this study distributed an electronic questionnaires for investigating the occupant’s preference in terms of window (size, glazing, function etc.).

4.2 Case Study in Najran

The villas shown below are a government project that has been built in several cities in the Kingdom of Saudi Arabia (Figure 36). Moreover, this is a prototype that has been approved by the Ministry of Housing. This study has chosen this case to investigate the impact of window-Blinds design in Najran city.

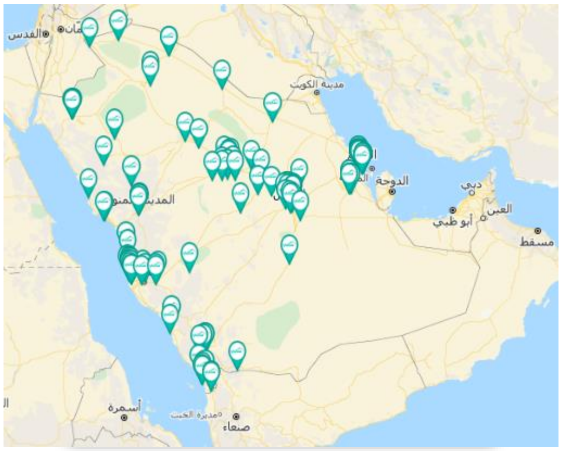


Figure 36 Map of Saudi Arabia showing where the selected Villa located.

So that the number of projects containing the same model in the Kingdom of Saudi Arabia has reached (124 projects) that have been distributed to the administrative regions so that the total number of typical villas exceeded 145,929 housing units, table No. 8 shows the number of projects and housing units in some regions of the Kingdom.

Najran a region of Saudi Arabia, located in the south of the country along the border with Yemen. Najran region is located in the southwest between the Kingdom of Saudi Arabia 17.48333°N 44.11667°E. It has an area of about 365000 km2 plus the area of Kharkhir. The neighborhood project is laid in 1,260,000 m2. The neighborhood is contains with (1,061) units "Villas" each unit has a total gross area of about 238 m2 (Figure 37 to 42).

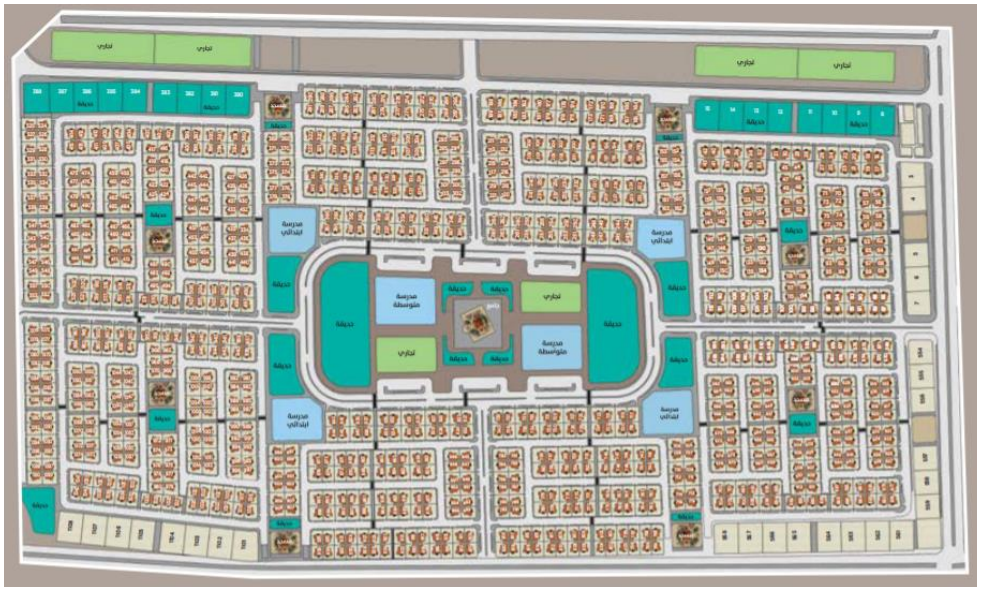


Figure 37 An aerial view of the site of the housing project area of Najran

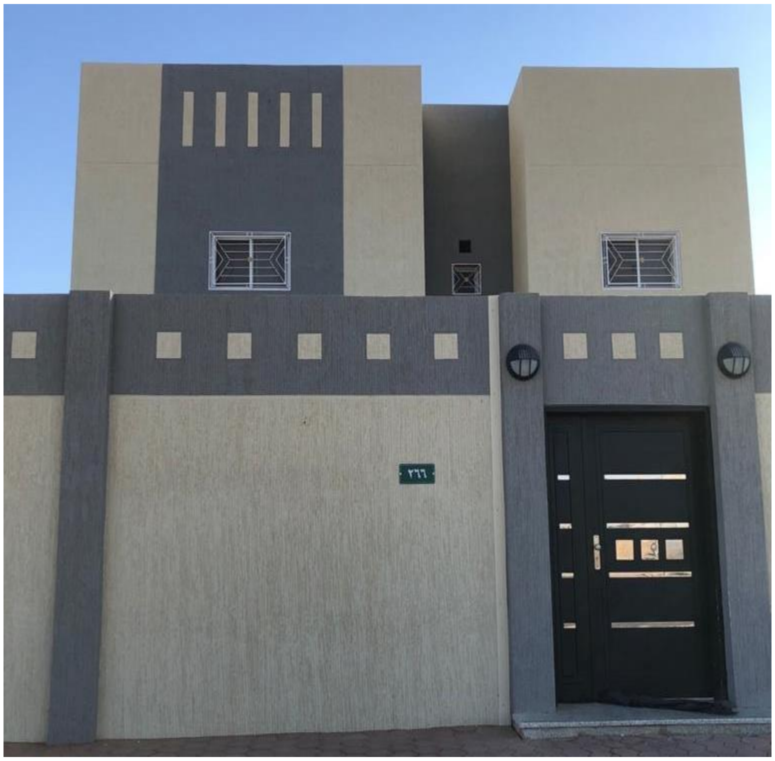


Figure 38 Najran Housing in Najran

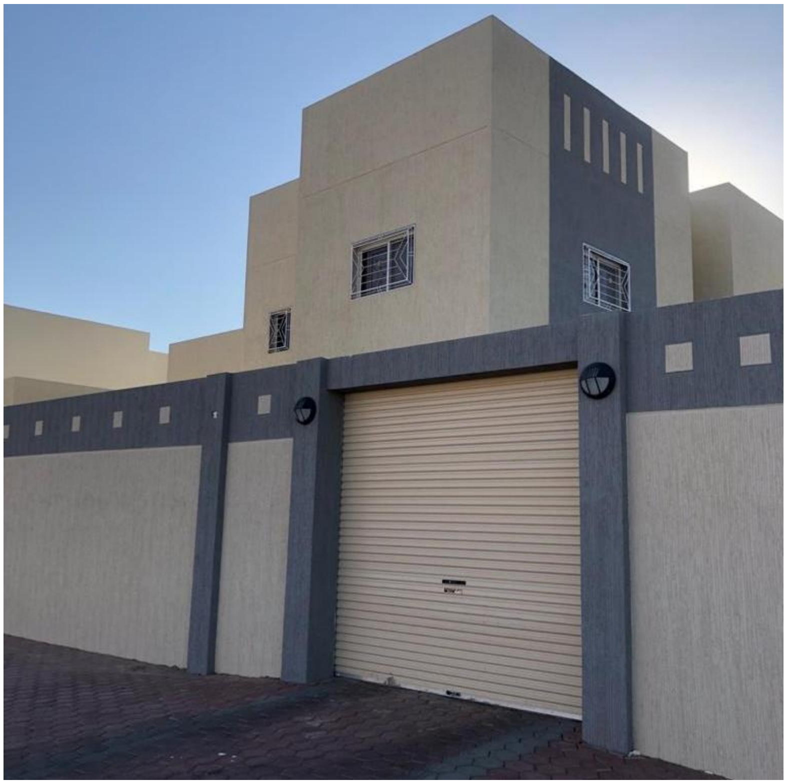


Figure 39 Najran Housing in Najran

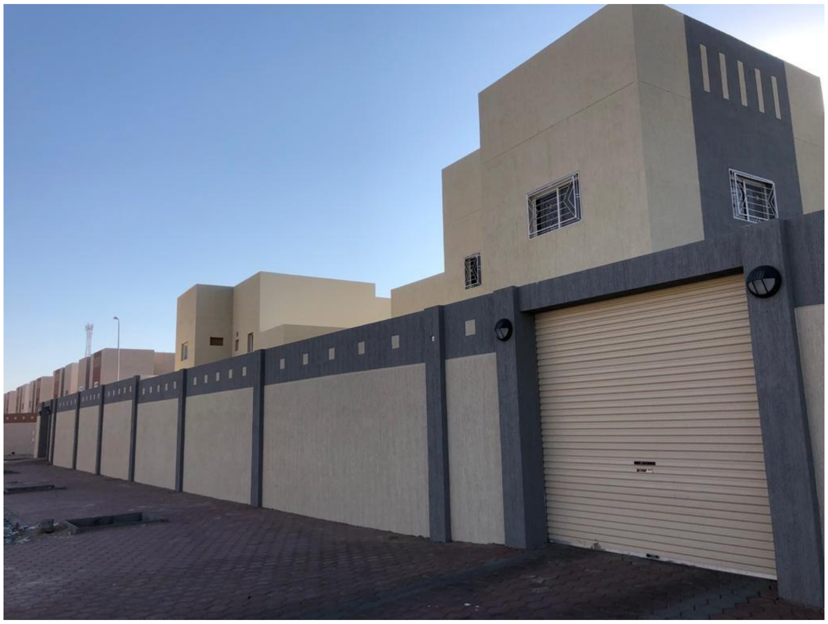


Figure 40 Najran Housing in Najran

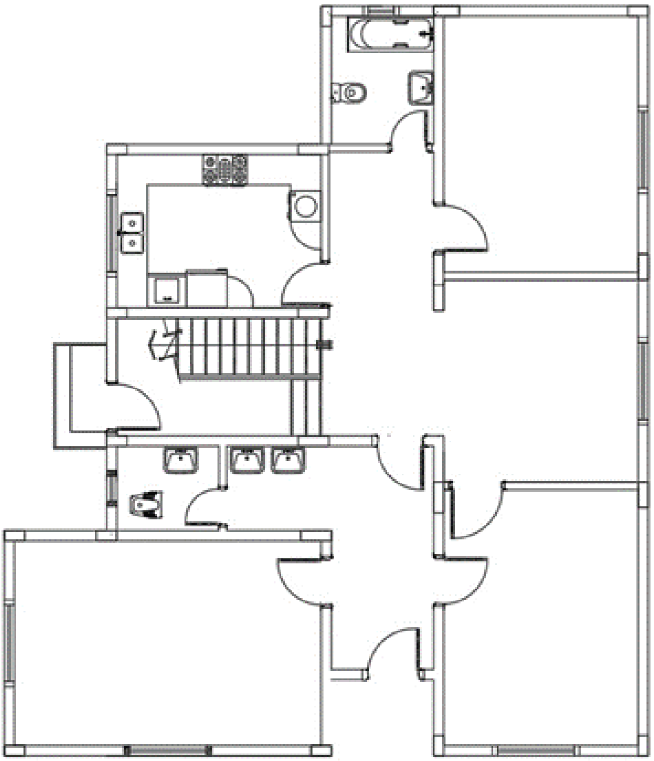


Figure 41 Ground Floor of the villa. (Source: Ministry of housing)

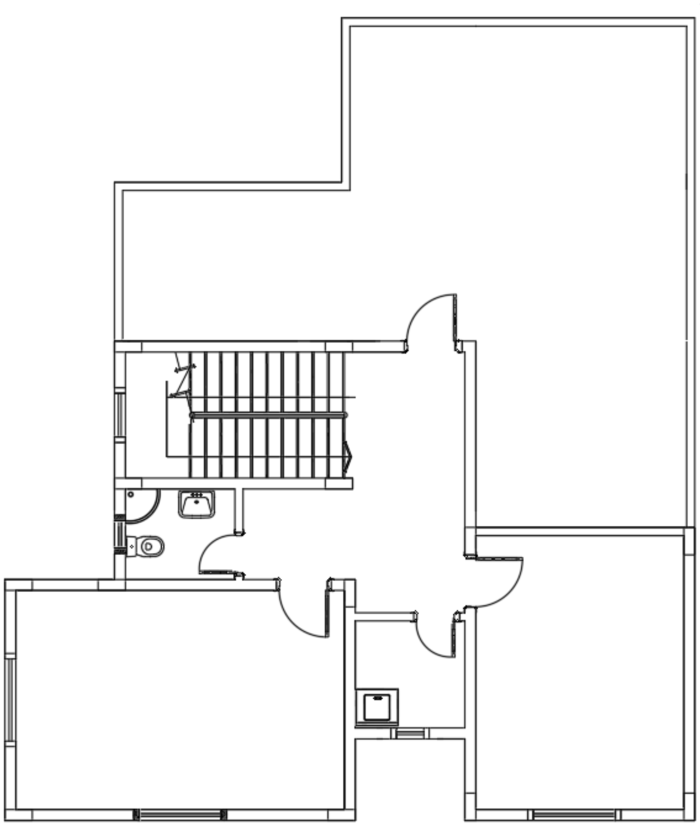


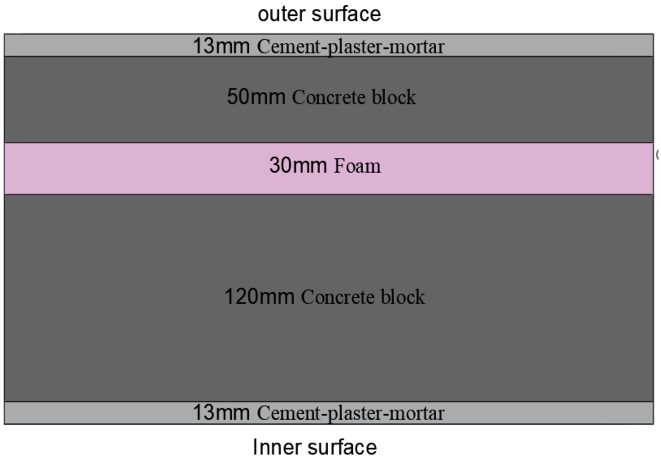
Figure 42 First Floor of the Villa (Source: Ministry of housing)

4.2.1 Building Envelope Materials

4.2.1.1 External Walls Materials

The construction of a case study villa wall consists of several layers. As shown in Table 8. and Figure (43) the exterior walls' components. It shows the wall's components, the type of thermal insulation used, and each layer's thickness.

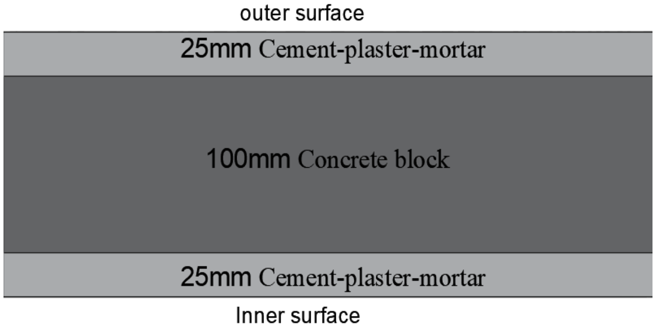
Table 8: External wall Materials

Material	**Thickness (mm)**	
Cement-plaster-mortar	13	 outer surface 13mm Cement-plaster-mortar 50mm Concrete block 30mm Foam 120mm Concrete block 13mm Cement-plaster-mortar Inner surface **Figure 43 Cross-section of the external wall**
Concrete block	50	
Foam	30	
Concrete block	120	
Cement-plaster-mortar	13	
Total	226	

4.2.1.2 Internal Walls Materials

The construction of a case study villa wall consists of several layers. As shown in Table 9. and Figure (44) the interior walls' components. It shows the wall's components, the type of thermal insulation used, and each layer's thickness.

Table 9: Internal Walls Materials

Material	**Thickness (mm)**	
Cement-plaster-mortar	25	 outer surface 25mm Cement-plaster-mortar 100mm Concrete block 25mm Cement-plaster-mortar Inner surface **Figure 44 Cross-section of the internal wall**
Concrete block	100	
Cement-plaster-mortar	25	
Total	150	

4.2.1.3 Roof Materials

The ceiling of the case study consists of several layers. As shown in Table (10) and (Figure 45) provide a model for the base case's Roof. Moreover, explain the types of ceiling components, type of heat insulation used, and each layer's thickness.

Table 10: Roof Materials

Material	**Thickness (mm)**
Concrete Tiles (Roofing)	25
Cement-plaster-mortar	20
Sand and gravel	40
XPS Extruded Polystyrene – HFC BLO	60
Rubber	3
Concrete, Reinforced (with 2% steel)	150
Cement-plaster-mortar	20
Total	318

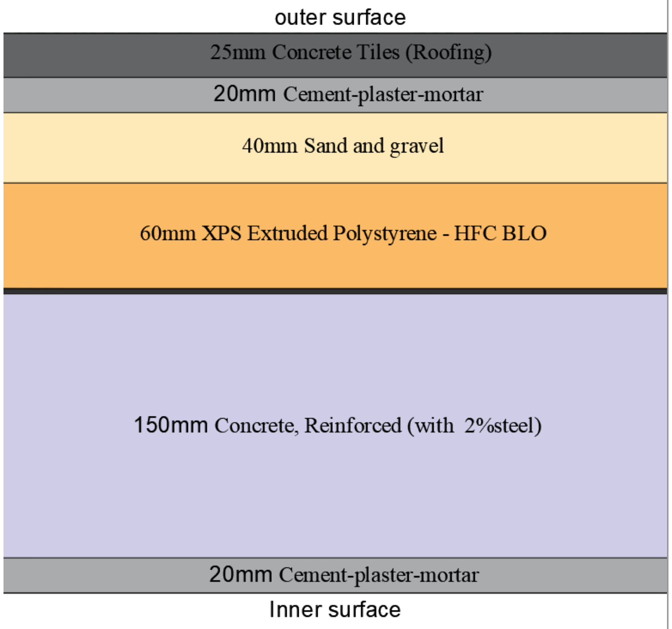
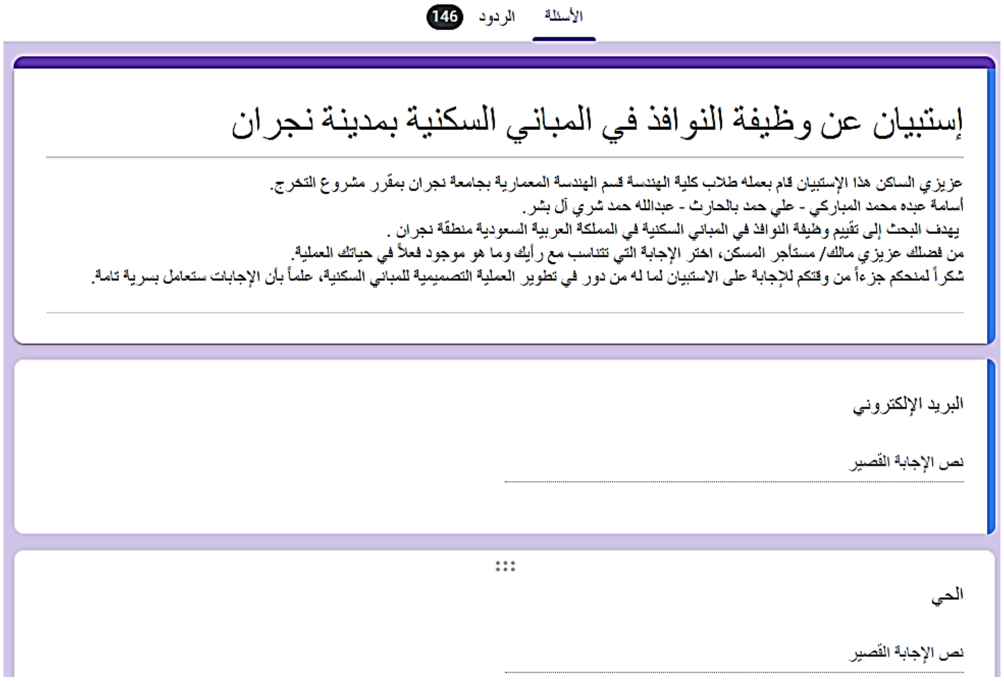

outer surface
25mm Concrete Tiles (Roofing)
20mm Cement-plaster-mortar
40mm Sand and gravel
60mm XPS Extruded Polystyrene - HFC BLO
150mm Concrete, Reinforced (with 2%steel)
20mm Cement-plaster-mortar
Inner surface

Figure 45 Cross-section of the Roof

4.3 Tenant's preferences in terms of window openings: Questioner surveying

This study made a questionnaire to get a clear picture on the occupant's preferences in related to their idea on the function of window openings in their homes window glazing and size. Asking the tenants to show their satisfaction with windows' role in entering daylighting.

Figure (46) shows the first page of the electronic questionnaire. While figure (47) showing the areas from which the responses to the questionnaire were collected. The number of respondents to this questionnaire was (146 people) up to the date where this report is transcribed.



إستبيان عن وظيفة النوافذ في المباني السكنية بمدينة نجران

عزيزي الساكن هذا الإستبيان قام بعمله طلاب كلية الهندسة قسم الهندسة المعمارية بجامعة نجران بمقرر مشروع التخرج.
أسامة عبده محمد المباركي - علي حمد بالحارث - عبدالله حمد شري آل بشر.
يهدف البحث إلى تقييم وظيفة النوافذ في المباني السكنية في المملكة العربية السعودية منطقة نجران .
من فضلك عزيزي مالك/ مستأجر المسكن، اختر الإجابة التي تتناسب مع رأيك وما هو موجود فعلاً في حياتك العملية.
شكراً لمنحكم جزءاً من وقتكم للإجابة على الاستبيان لما له من دور في تطوير العملية التصميمية للمباني السكنية، علماً بأن الإجابات ستعامل بسرية تامة.

البريد الإلكتروني

نص الإجابة القصير

الحي

نص الإجابة القصير

The figure 46 Questionnaire interface

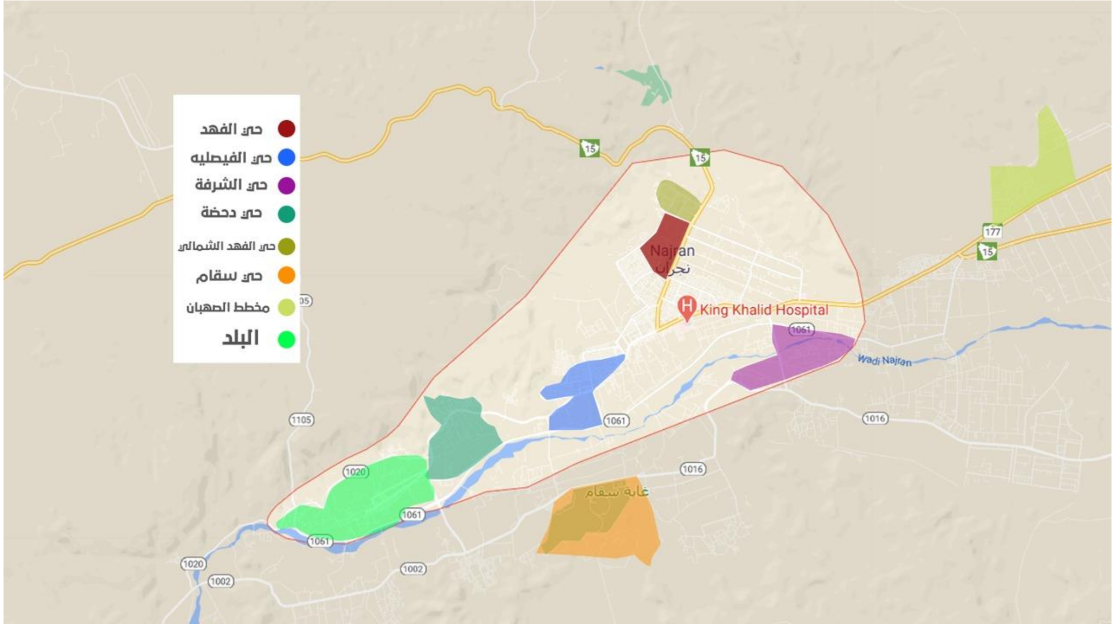


Figure 47 The areas of Najran city where the responses to the questionnaire were collected.

4.3.1 Glazing Type

The survey asked occupant is to show their idea on the glass type. This question was set to understand the relation between the privacy, daylighting and other variables. The most standard glass types used in windows, including (single clear glass-tinted single glass-double glazing-reflecting-glass with grid). The respondents show a high preference to the tinted glazing either single or double with 32.2% and 31.5 % respectively.

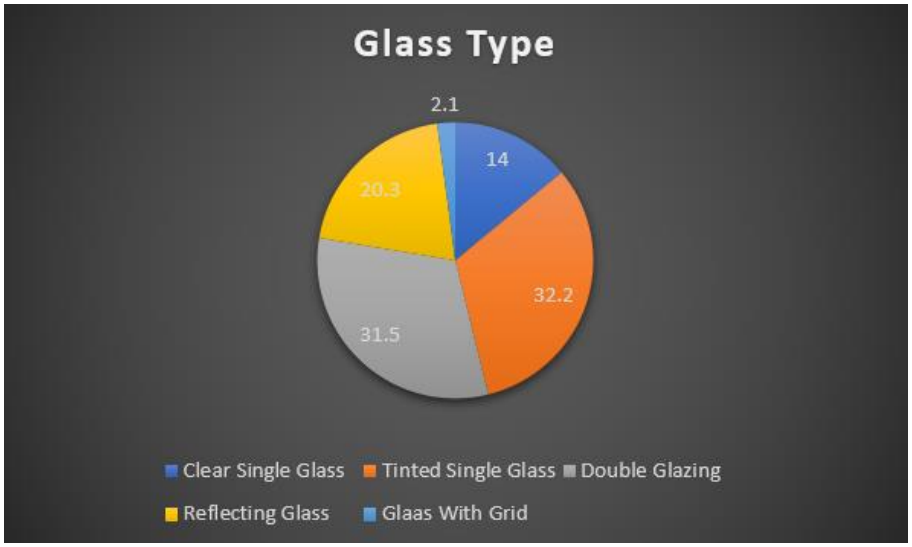


Figure 48 the type of glass used in most buildings in Najran.

4.3.2 Glazing-tints or Curtain

We also know that one of the benefits of windows is to allow light transmittance, so most want to control the amount of light entering through the window or block it, and besides that, the solar heat entering the house is also blocked. One of our questions was about this type of control. However, the majority with 89.5% prefer using the curtain, so they can control easily the opening and outdoor connection.

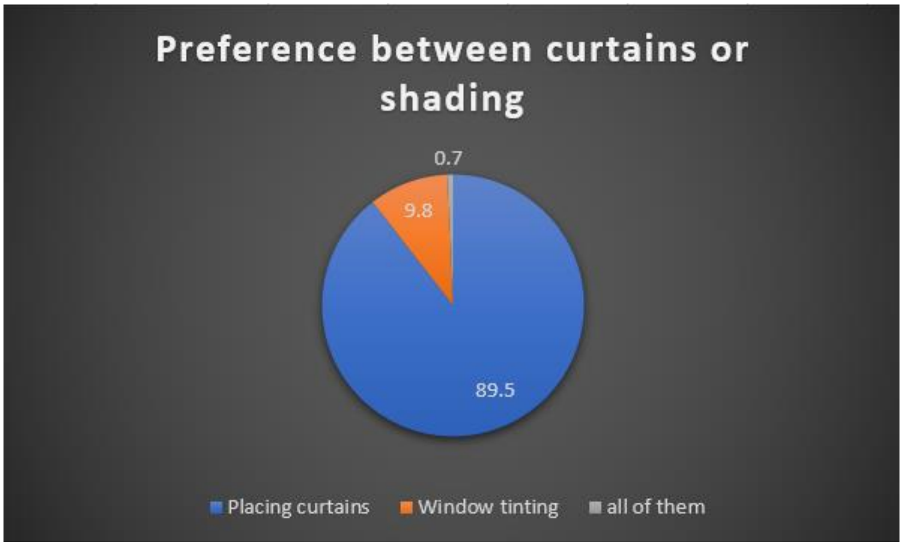


Figure 49 respondents' preference for curtains or window shades.

4.3.3 Artificial light or daylighting

There are two types of lighting, natural light and artificial lighting. Natural lighting is an essential source of light, free and useful in addition to its many advantages. However, to know to what extent the occupants prefer during the daytime. Figure 50 shows that more than 92% of the respondents cited their preferences to the daylighting. This is an indication to the presences of a large window openings.

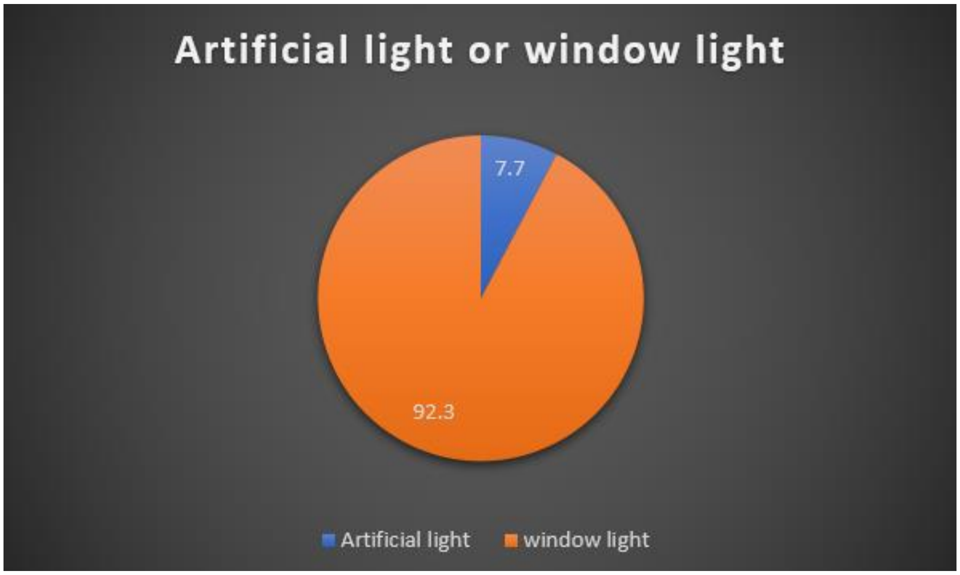


Figure 50. the respondents' opinion of the preference between artificial light or window light.

4.3.4 Large or small window openings.

Figure 51 shows that 92.3% of the respondents prefer large windows. The large window provides daylighting, connection with the outside of the house and give a feeling of visual comfort. However, large windows allowing more heat gain indoors. So that this study aims to increase the size of the window while providing solutions to control the direct solar radiation and heat gain indoors.

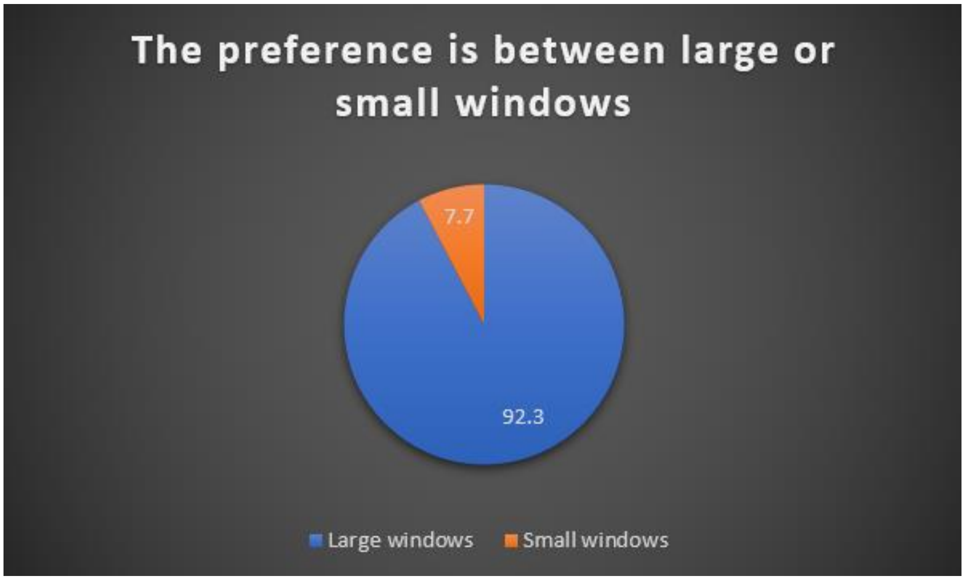


Figure 51 respondents' opinion of the preference between large or small windows

In summary, referring to the result of the questionnaire survey where the tenants show preferences to the large windows. In addition, to the Saudi code that cited a WWR of 25%, this study will aim to increase the size of windows of a selected villa that was found with a WWR of 6%. Then to simulate window blinds' function in controlling residential buildings' energy consumption in Najran city.

Chapter 5

BUILDING MODELLING AND SIMULATION

5.1 Introduction

Simulation and building energy modeling are the easiest way for engineers to understand building performance in the early design phase. Moreover, it contributes to obtaining essential benefits such as reducing energy consumption, reducing cooling load consumption. Simulations are matching and estimating alternatives for energy design in buildings and improvement thereof.

5.2 Modeling the base case villa using Design Builder

In this section, we used a modern software tool called Design Builder to develop a simulation model for the base case based on the information provided in the previous section. The Design Builder app provides a wide variety of tools for drawing and adding blocks that ultimately shape and composition. Also, we created DXF real house floor plans and then imported them on Design Builder to work on. All we need is the DXF trace we imported to create the home levels all individually. This stepwise approach that we followed facilitated the process of building the Study Case Model (Villa). Although several areas in the house, the application made it easy and made each floor only one area. As shown in figurer 52 the developed model with the North Index, starting to study the primary situation in light of the climate data in Najran; the following paragraphs show every aspect of the necessary model development (building cover, air conditioning system, lighting, etc.)

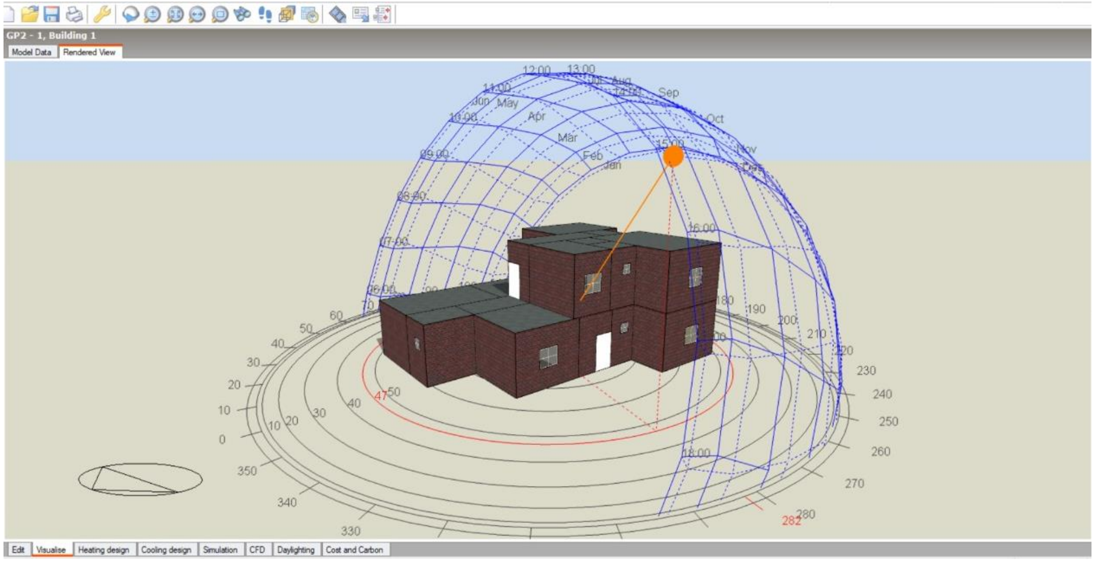


Figure 52 Rendering of the base case with the sun path diagram at 3 pm, 27th May.

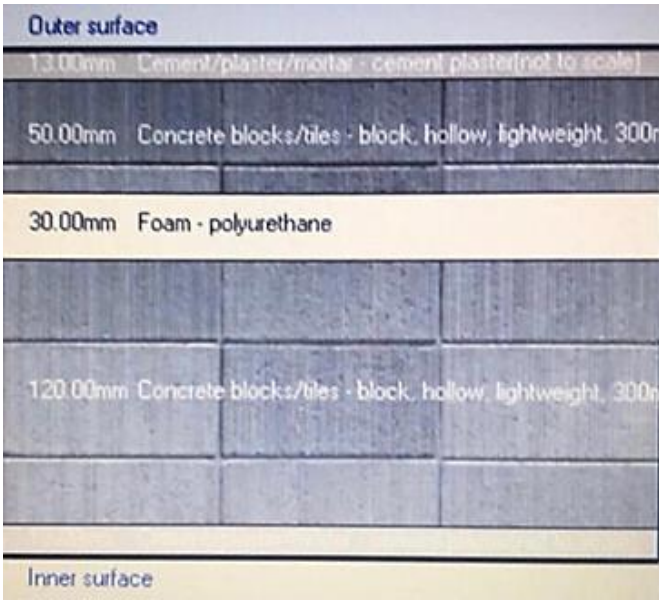
5.3 Construction of the simulated building

Depending on the data that I refer to in Chapter Four, building cover systems are discussed and explained in the program. All the details are clarified.

5.3.1 Wall materials

5.3.1.1 External wall

The most exposed to the weather, and specifically the heat, is the outer envelope of the building, the most important of which is the outer wall, as it acquires heat from the outside and conducts it inside the building if it is not isolated, so the insulation of the outer walls is essential to improve the building energy efficiency and maintain the temperature inside the building and reduce the consumption of cooling energy in summer and heating in winter, The photo details the materials used to build the exterior walls



Outer surface

13.00mm Cement/plaster/mortar - cement plaster(not to scale)

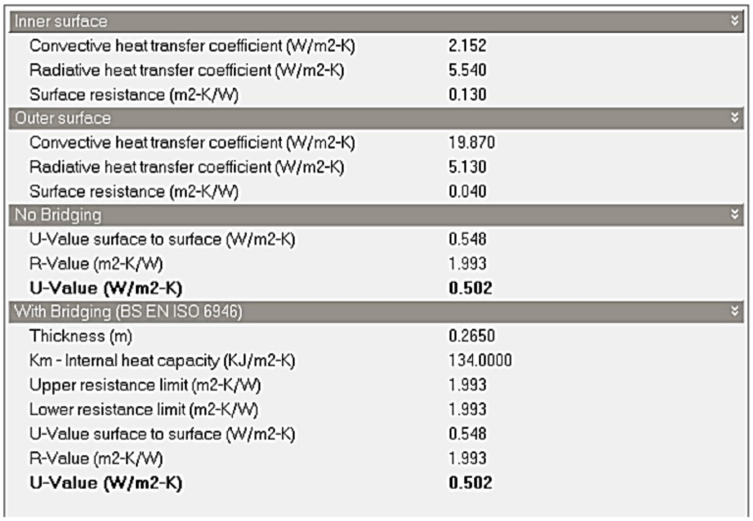
50.00mm Concrete blocks/tiles - block, hollow, lightweight, 300

30.00mm Foam - polyurethane

120.00mm Concrete blocks/tiles - block, hollow, lightweight, 300

Inner surface

Figure 53 External-wall



Inner surface	
Convective heat transfer coefficient (W/m2-K)	2.152
Radiative heat transfer coefficient (W/m2-K)	5.540
Surface resistance (m2-K/W)	0.130
Outer surface	
Convective heat transfer coefficient (W/m2-K)	19.870
Radiative heat transfer coefficient (W/m2-K)	5.130
Surface resistance (m2-K/W)	0.040
No Bridging	
U-Value surface to surface (W/m2-K)	0.548
R-Value (m2-K/W)	1.993
U-Value (W/m2-K)	**0.502**
With Bridging (BS EN ISO 6946)	
Thickness (m)	0.2650
Km - Internal heat capacity (KJ/m2-K)	134.0000
Upper resistance limit (m2-K/W)	1.993
Lower resistance limit (m2-K/W)	1.993
U-Value surface to surface (W/m2-K)	0.548
R-Value (m2-K/W)	1.993
U-Value (W/m2-K)	**0.502**

Figure 54 Values show the materials used in Model.

5.3.1.2 Internal wall

The internal walls and their effect on thermal transfer is an essential point in this study, and here we explain the details of the materials used in building the internal walls (from the inside to the outside).

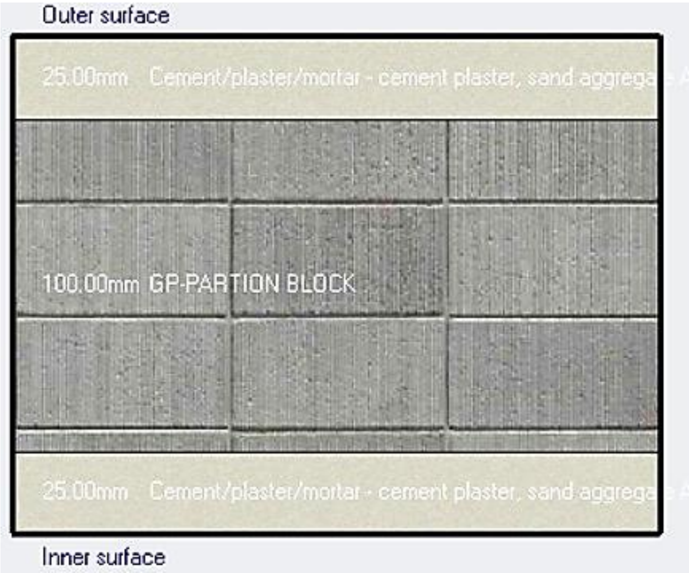
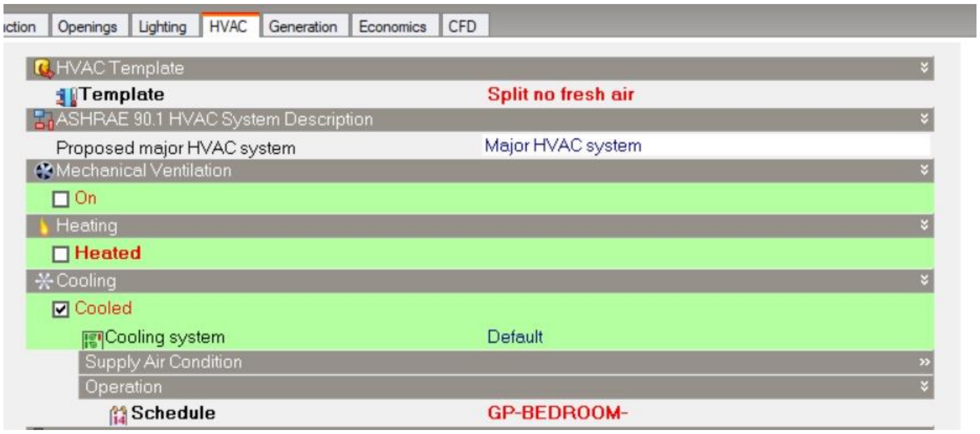

Outer surface
25.00mm Cement/plaster/mortar - cement plaster, sand aggrega
100.00mm GP-PARTION BLOCK
25.00mm Cement/plaster/mortar - cement plaster, sand aggrega
Inner surface

Figure 55 Internal wall.

5.4 Cooling System Definition

The cooling system is essential in regulating the temperature inside the building, and the system used in this model is (Mini-Split); mini splits have two main components: an outdoor compressor/condenser and an indoor air-handling unit. A conduit, which houses the power cable, refrigerant tubing, suction tubing, and a condensate drain, links the outdoor and indoor units.



Template Split no fresh air

Proposed major HVAC system: Major HVAC system

☐ On

☐ **Heated**

☑ Cooled

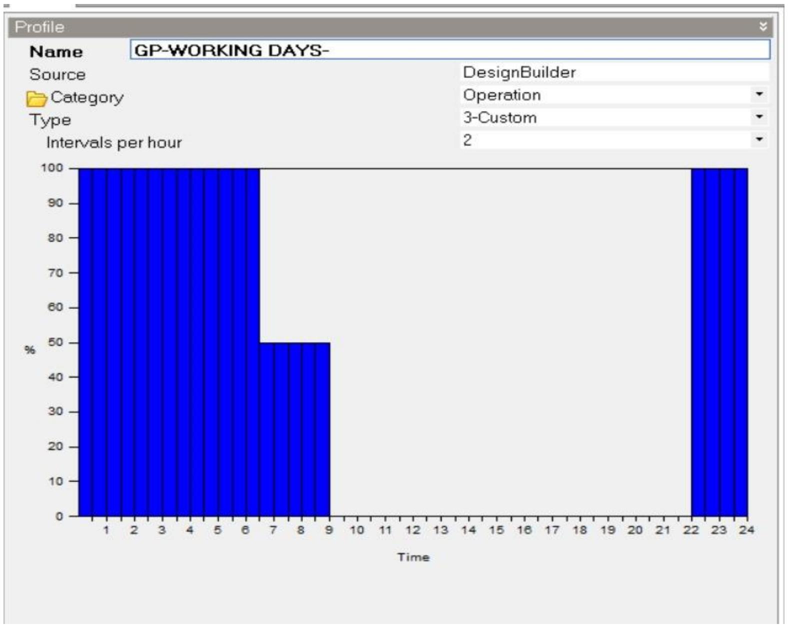
Cooling system: Default

Schedule GP-BEDROOM-

Figure 56 Air conditioning system in the building

Figure 57 The system used in adapting the building

The master bedroom's cooling degree was set to 22 ° C and analyzed because it is an essential space in the studied model. As for the on and off mode, As shown in figure (58, 59) the extent of the operation of the master bedroom by the users.



Profile

Name GP-WORKING DAYS-

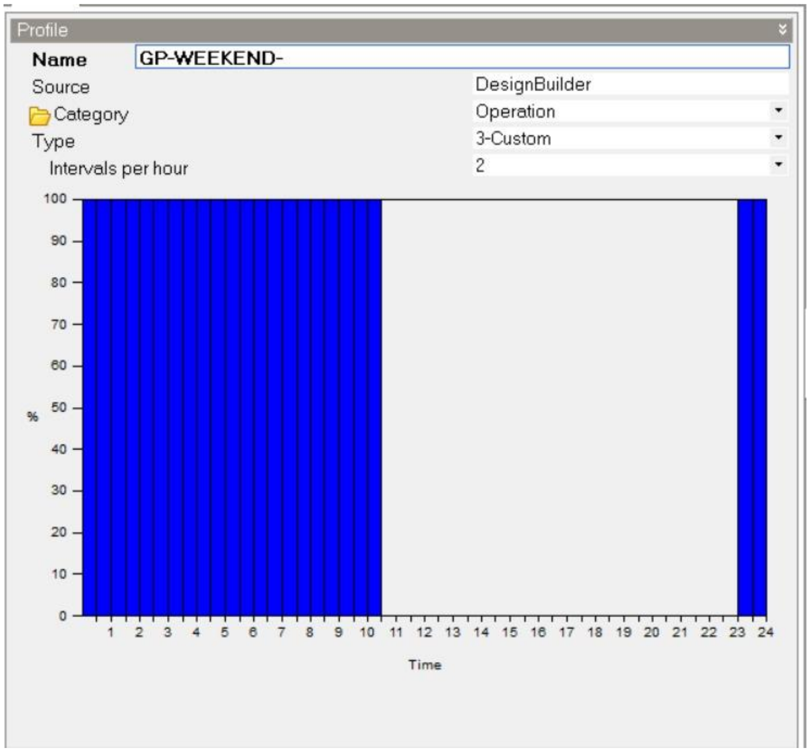
Source: DesignBuilder

Category: Operation

Type: 3-Custom

Intervals per hour: 2

Figure 58 operating time of A.C. in the master bedroom during workday



Profile

Name GP-WEEKEND-

Source: DesignBuilder

Category: Operation

Type: 3-Custom

Intervals per hour: 2

Figure 59 operating time of A.C. in the master bedroom during the weekend.

5.5 Calibrating the base case model

5.5.1 Annual energy consumption

Table11 illustrates the simulation output results for energy consumption from Design Builder programs. It is assumed to compare to the result from the actual case of a selected villa.

Table 11 window size comparing to a 6% of an actual villa

Independent variable	**Season**	**EXPERIMENTS**	***Dependent variable*:**		
			Cooling energy	***Lighting energy***	**Energy Per Total Building Area [kWh/m2]**
Clear single glass	Annually	6% glazing-BC	9066.78	2,623.77	**65.37**

5.5.2 Limitation of calibration and method justification

As a case study (actual villa) has been built in Design Builder program, it is assumes to have a calibration action to show the identical of the model (base case) to the actual case study. The selected villa that is amongst the project of Ministry of Housing in Najran city. However, due to many limitations that are:

- There is no villa occupied for the past 12 months and no electricity pills.
- Difficulty of conducting a site measuring to heat gain during the summer of 2020 due to the coronavirus lockdown.
- It will be a useful method to build a model in Design Builder using the data available in chapter 4 it is a Design Builder case to investigate the impact of window-blinds.

Although there is no accurate data from the case study as mentioned earlier, it is useful to stand on the energy consumption of several houses in Najran city. It is to give an indication to residential building consumption that may imitate it to carry the window design with blinds using DesignBuilder in this study. Several electricity bills were collected to support the study. The bills are reviewed monthly and annual consumption through the electronic bill application as in figure 60. Five bills that were available to the authors, were reviewed. Table 11 and Figure 61 illustrate a variation between houses in terms of energy consumption. The average annual energy consumption was 63.42 kWh/m2/y. Figure 61 shows the variation during the year. Cooling energy causes the majority of electricity pill as in summer months.

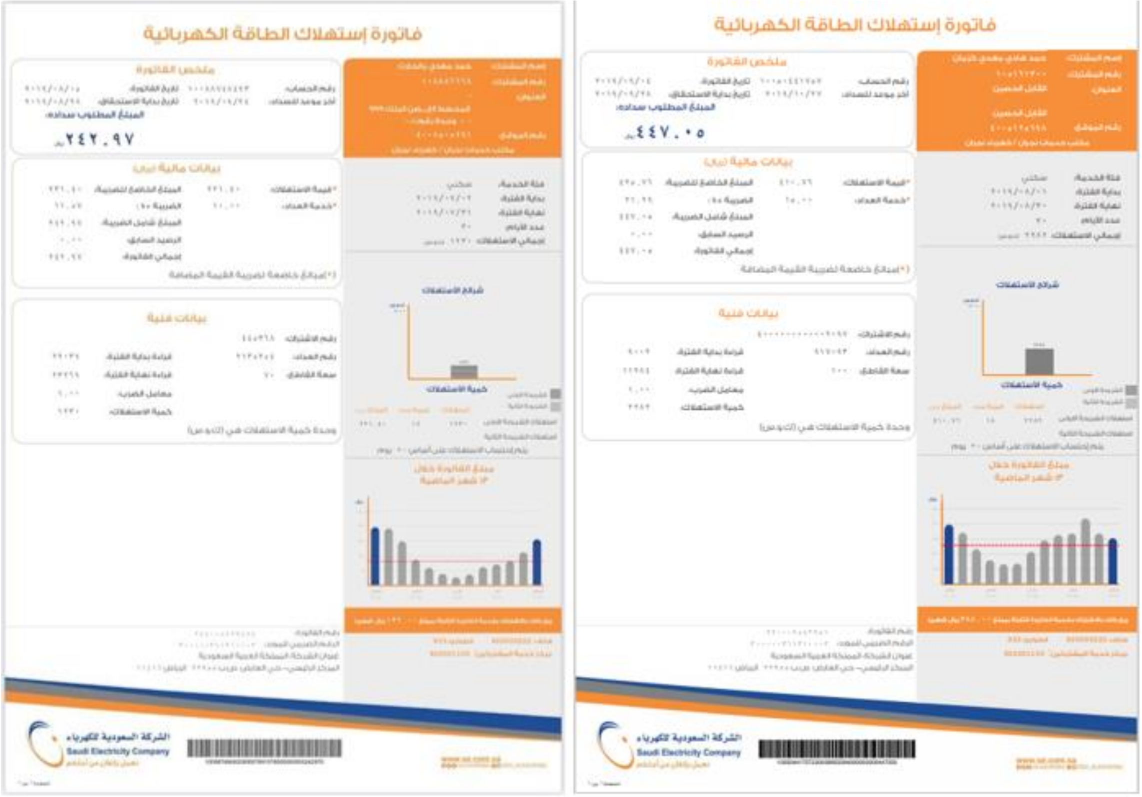


Figure 60 Some electricity bills for the respondents

Table 12: shows the energy consumption of a number of bills for residents of Najran region

Building number	Account number	Region	Users number	Gross area m2	Annual electricity consumption kwh/y	Annual consumption kwh/m2/y
1	10088749571	Najran	5	165	5750	34.9
2	10088748493			165	9333	56.6
3	10050441757			195	22832	117
4	10051126338			192	14564	75.8
5	10049989272			324	10635	32.8
Average Electricity Consumption (KWh/m2/y)					12622.8	63.42

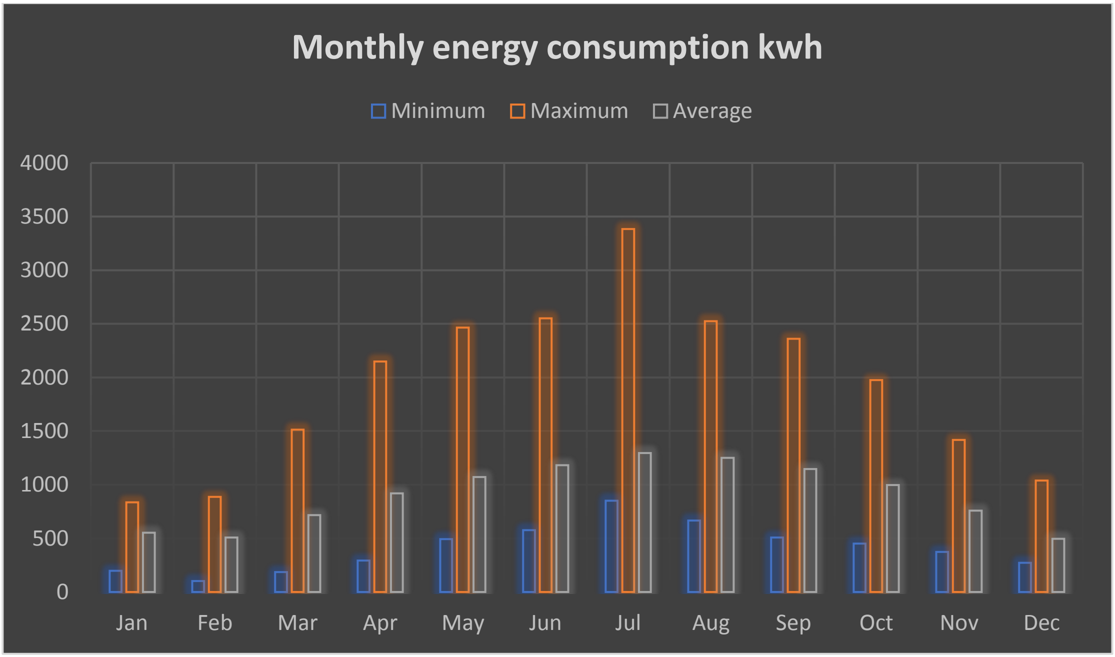


Figure 61 Tenants' preference for the window openings design in residential buildings in Najran city.

CHAPTER 6

Optimization of fenestration system: low-e glass integrated with window-blinds: simulation

In this chapter, the study presents and analyzes the results of the experimental work using simulation tool. The model built using Design Builder simulation program. Model was built using a prototype that has been approved by the Ministry of Housing. However, the study found that drawings and actual villas are similar in window details. The WWR of the actual villa was 6%. According to the result of questioner survey and the Saudi code, the wide windows are preferable in residential buildings. This study aiming to increase the WWR up to 20%. The study starts simulating the energy consumption with 6% WWR, which is an actual case. Then examining the WWR of 10%, 15%, 20% clear glass and then WWR of 20% with changing glazing into low-e glass.

This study uses **clear glass with WWR of 20%** as a Reference Case (RC) to investigate the impact of window blinds (types and position) on energy consumption of the modeled villa.

6.1 optimizing window size and glazing type for daylighting, heat control and outdoor connection.

6.1.1 Window glazing size and daylighting

This study intended to change the window glazing size responding to the occupant preferences that was found in questionnaire survey discussed in chapter 4. Figure 62 (A, B,C,D) shows daylight illuminance distribution on the ground floor of the base case WWR6%, WWR10%, WWR15% and WWR20% (clear glass). It is noted that daylight illuminance was increased, and this cause a reduction in energy consumption of electrical lighting as illustrated in table 12. Comparing the daylight illuminance between 20% clear glass and 20% low-e the results show minimal reduction in daylight illuminance as illustrated in color contour of 20% clear glass and 20% low-e. However, for balancing between allowing more daylighting and prevent heat gain the study uses clear low-e glass with 20%. From here on, the study uses a WWR of 20% with clear glass as a reference case to investigate the impact of low-e glazing and window blinds in controlling the direct solar radiation in a designed model.

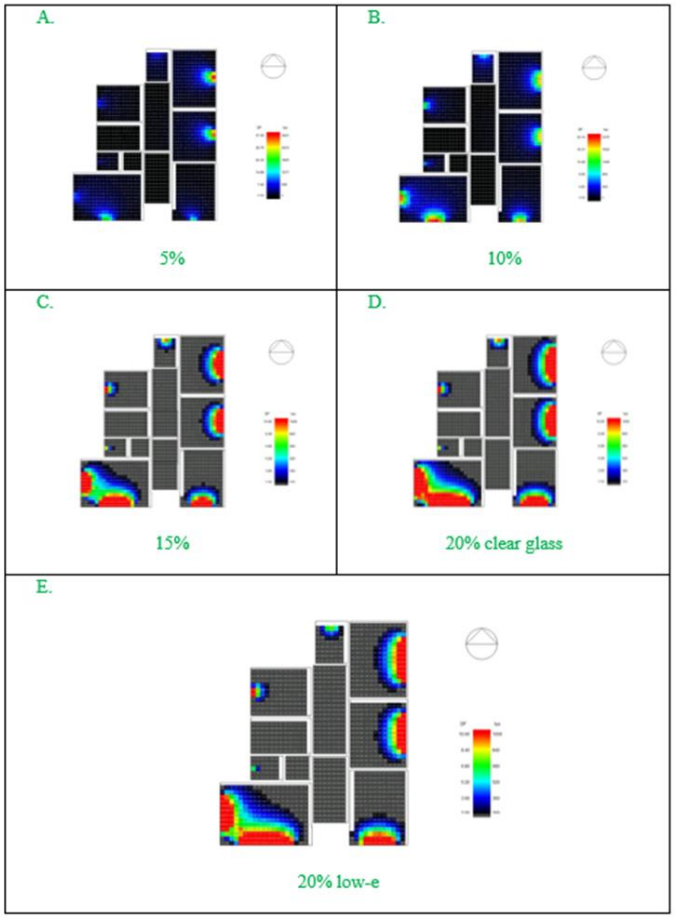


Figure 62 Colored couture for daylighting illuminance with different window sizes.

6.1.2 Window glazing size against energy consumption

The study changes the window size of the base case to attain daylighting and outdoor connection according to the occupants' preference shown in chapter 4, and Saudi code of WWR 25%. Energy consumption is studied and simulated of the WWR 6%, 10%, 15% and 20%. Table 13 and figures (63 and 64) illustrate the cooling energy of all investigated glazing size and type. It was found that energy consumption is increased with increasing the window size. These results were expected, and a sacrifice to make the window flexible to meet the tenant's preferences and needs.

Table 13 window size comparing to a 6% of an actual villa

Independent variable	**Season**	**EXPERIMENTS**	***Dependent variable*:**			***Reduction %***
			Cooling energy	***Lighting energy***	**Energy Per Total Building Area [kWh/m2]**	
Clear single glass	Annually	6% glazing-BC	9066.78	2,623.77	65.37	
		10% glazing	10,010.96	2,587.96	69.86	
		15% glazing	11232.78	2561.88	75.77	
Reference case		20% glazing	13566.42	2585.78	87.05	

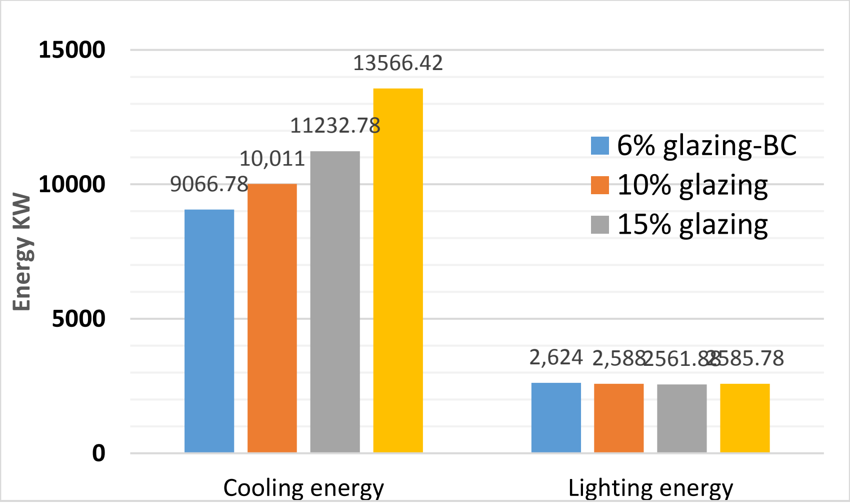


Fig. 63 Annual cooling and lighting energy (kWh) of the base case with different glazing size.

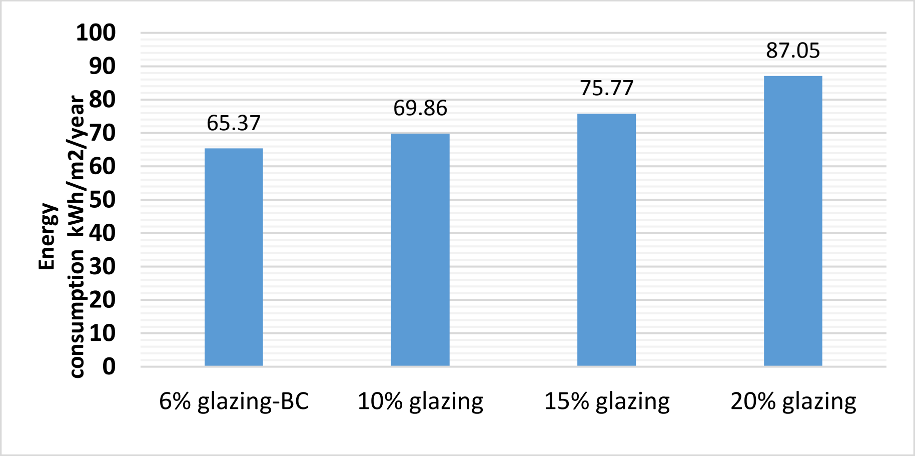


Figure 64 Annual Energy consumption (kWh/m2) with increasing the window glazing size of the base case.

6.1.3 Optimizing window glazing for heat gain control.

Before the investigation of the window blinds, it is advisable to enhance window performance by low-e glass. It is to control the heat gain due to the variation between outdoor and indoor. Figure 64.a shows a reference case of clear glass of 20%WWR. The high variation between indoor/outdoor air temperatures during the daytime was about 8 °C. This high variation makes the window glazing as a main contributor to heat gain. So that the study changed the window glazing to be a double low-e glazing that is a common type available in the market for controlling heat gain whereas, window blinds were used for blocking the direct solar heat gain.

Table14 and figure 66 show a comparison between a reference case of clear glass, 20% WWR and a suggested glazing of double low-e to the same WWR of 20%. A reduction in energy consumption was found of about **11%** when using low-e glazing.

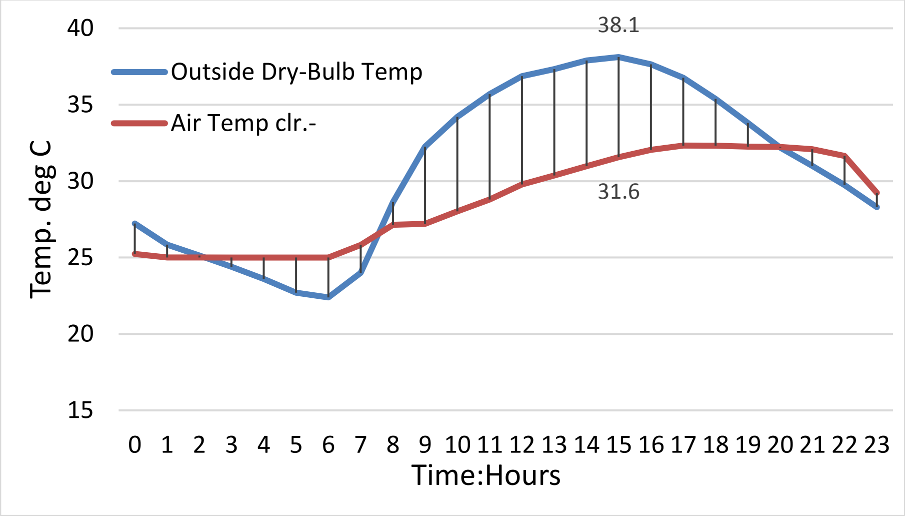


Figure 65. Air temperature variation between outdoor and indoor (DesignBuilder, based on Najran weather file.)

Table 14 the contribution of low-e glass in reducing energy consumption

Independent variable	**Season**	**EXPERIMENTS**	***Dependent variable*:**			***Total reduction***
			Cooling energy	***Lighting energy***	**Energy Per Total Building Area [kWh/m2]**	
Single clear		20% glazing	13566.42	2585.78	87.05	
Double low-e-clr	Annually	20% glazing	11783.48	2615.14	77.85	11%

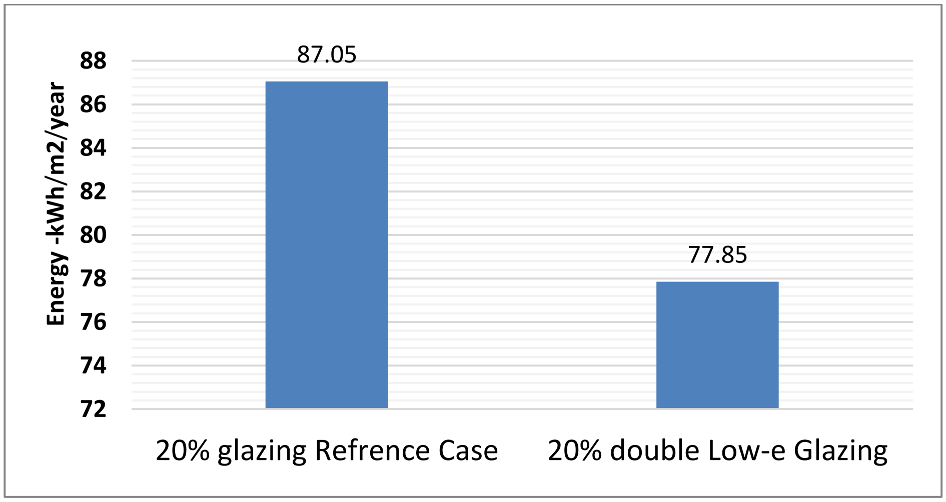


Fig. 66 annual energy consumption (kWh/m^2) with 20% WWR clear glazing vs. 20% WWR double low-e.

6.2 Window blinds as a potential energy saver

External shading devices are efficient in blocking direct solar radiation before it transmits through the glazing, and orientation is crucial for their performance. Horizontal shading is preferable for south-orientated windows, and vertical shading is more suitable for east/west orientation. However, east and west window receives the domain of direct solar radiation. They need to be totally closed to prevent direct solar beam. Window blinds may play this role.

This study will examine different position of blinds and different type. The window shading devices can be positioned in one of four ways: ·

1-**Inside** - the window shading devices is positioned inside the zone.

- Venetian blinds
- Role blinds

2-**Mid-pane** - the window shading device is positioned between the inner pane and the second pane. ·

- Vientiane blinds
- Vientiane blinds- airflow

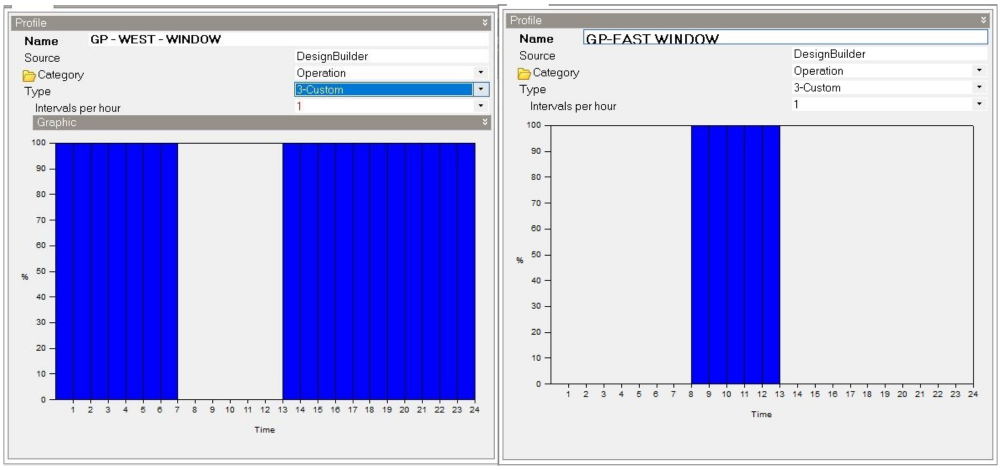
3-**Outside** - the shading devices positioned outside. ·

- Venetian blinds
- Role blinds

4-**Switchable** - select this option for electrochromic glazing in which case the outer pane is switched based on the shading control (below).

6.2.1 Optimizing the operation scheduled of window blinds to enhance energy savings

Making window openings smart, it is advisable to connect the window blinds to the Building Management System BMS. Schedule control was selected in this study when simulation the blinds systems. The Schedule is illustrated in figure 67. It is selected for east and west window openings that receives direct solar radiation increasing solar heat gain. However, window openings orient south, and north were incorporated with manual control to the blinds to suit the tenant’s visual comfort against glare. The low-e glass preventing heat gain due to the variation of temperature between outdoor and indoor.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Name GP - WEST - WINDOW
Source DesignBuilder
Category Operation
Type 3-Custom
Intervals per hour 1
Graphic

Profile
Name GP-EAST WINDOW
Source DesignBuilder
Category Operation
Type 3-Custom
Intervals per hour 1

Fig.67 blinds activity in the east and west windows

Figure 67 explains the role of the BMS room in controlling the system of opening and closing the blinds and its effective role in controlling the building systems to reduce high energy consumption and reduce the building's energy consumption.

6.2.2 The impact of outside potion of Window blinds (Venetian/ Role blind)

Theoretically, external Window blinds are efficient in blocking direct solar radiation before it transmits through the glazing. The heat energy through the system that affect cooling loads is illustrated in figure 68.

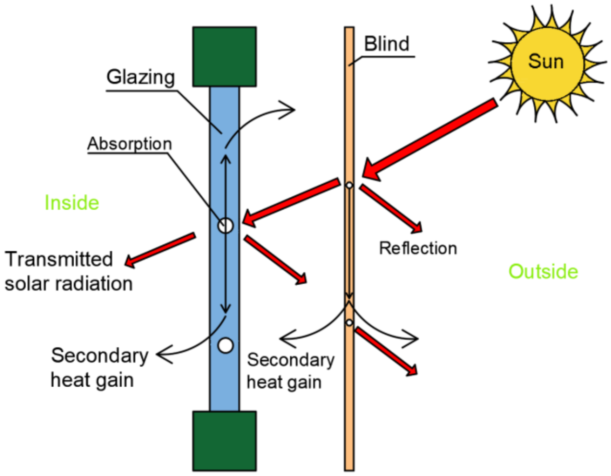

Figure 68. Schematic diagram of solar heat gain through window glazing and outside blinds.

Investigating outside position of window blinds will include Venetian Blinds and Roller blinds. External Venetian Blinds are the best choice when looking for efficient and cost-effective sun control with maximum flexibility and functionality. Modest in appearance, the blinds can be integrated into most facades, contributing to the building aesthetic without overpowering it. Whereas, roller blinds ensure full darkening of a room. In addition to that, roller blinds also assure additional sound and thermal insulation and protect the window against external influences.

Comparing these two types of blinds that were applied to the outside of the window, the study found that external roller blinds are better than venetian blinds in reducing energy consumption, as shown in table 15 and figures 69 and 70. The reduction was about 16%, as energy reduced from 87 to 73.84, compared to the reference case.

Table 15. A comparison between reference case and (Venetian & Roll blinds) outside.

Clear WWR **20% glazing vs. outdoor blinds**					
Independent variable		*Cooling energy*	*Lighting energy*	**Energy Per Total Building Area [kWh/m2]**	*Reduction* **%**
Blind position	Blind type				
Reference Case Single clear	20% glazing	13566.42	2585.78	87.05	--
Outside the room	Venetian Blind	11317.03	2579.47	76.27	12%
	Role blind	10805.21	2599.71	73.84	16%

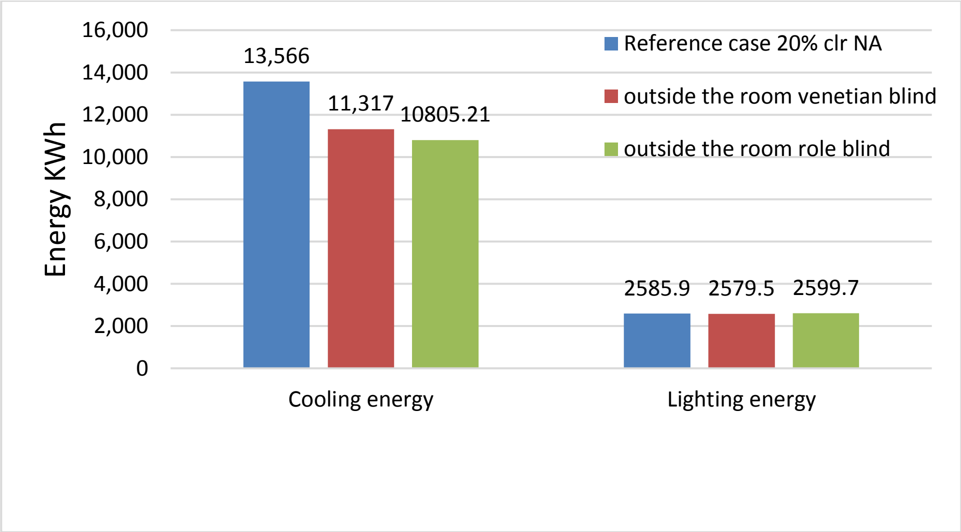

Figure 69 Annual cooling and lighting energy (kWh)

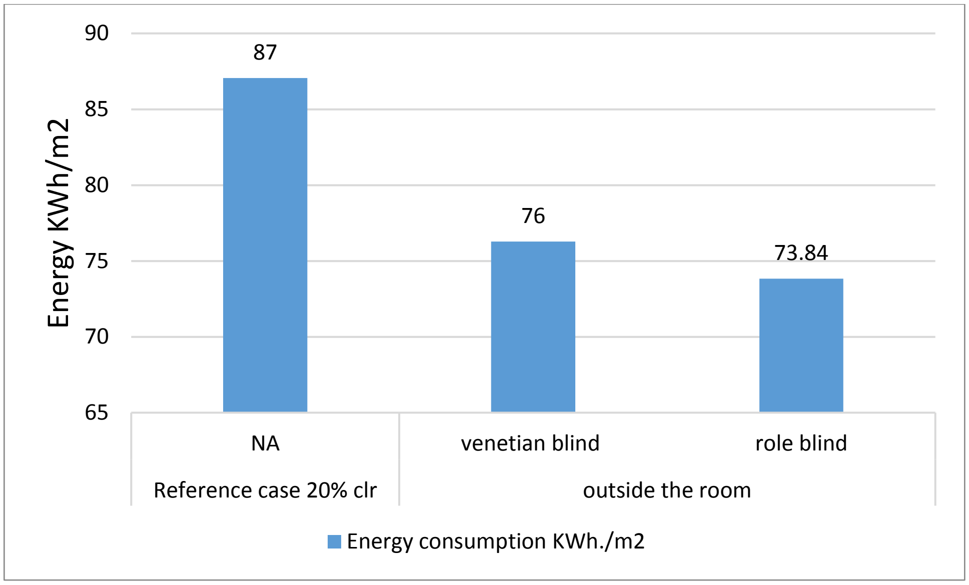

Figure 70 Annual Energy consumption (kWh/m^2)

6.2.3 The impact of mid-pane potion of Window blinds

The mid-pane Window blinds often refer to louvers, Venetian blinds, and shades mounted in between panes of the window glazing. In this section the study investigated tow systems inside the glazing system of the window. The venetian blind with tight glazing system while the second is the venetian blind with airflow outside-outside.

6.2.3.1 Mid-pane Venetian blind (without / with) airflow

Figure 71 and 72 show the concept of solar heat gain through the windows with venetian blind located in between the window glazing pane. Figure 71 without airflow, while figure 72 is to illustrate a unique mid-pane blinds that was designed with airflow. There are two layers of glass in the middle of the curtains, and the first layer of glass (outer) is open from both sides where the heat is discharged to the outside, which leads to less heat gain and reduced energy consumption.

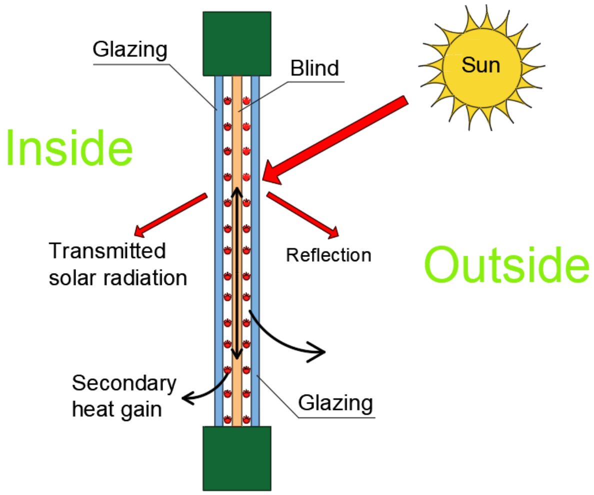

Figure 71 Schematic diagram of solar heat gain through window glazing and mid-pane blinds.

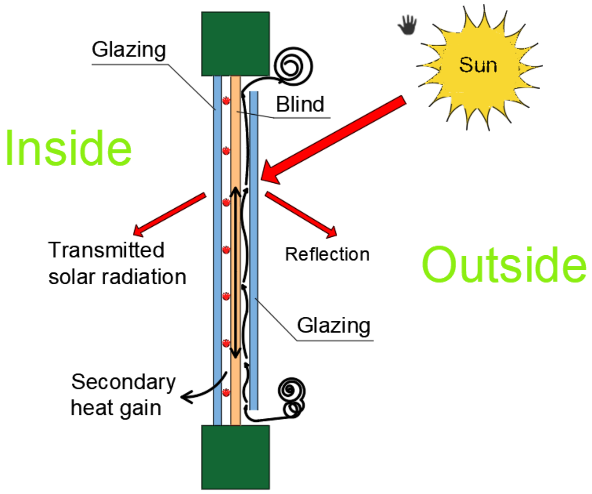

figure 72 Schematic diagram of solar heat gain through window glazing and mid-pane-airflow blinds.

Table 16 and figures 73 and 74 show the energy consumption of the selected blinds comparing to the reference case of clear glass. The results show that venetian blind in between the glazing of the window make a minimal contribution to the reduction of energy cooling of about 12 and 11%. Integrating this system with airflow does not show any useful contribution as well. It does not show a well controlling to heat gain that reflects on cooling loads. The reason is due to the high temperature outdoor and outer glazing that is low-e was made shorter to allow air flowing. This gap limits the performance of low emissivity glazing, so that heat gain increased and reflected on cooling energy.

Table 16. a comparison between reference case and (venetian / venetian air flow) **Mid-pane**.

Double low-e 20% glazing					
Independent variable		*Cooling energy*	*Lighting energy*	**Energy Per Total Building Area [kWh/m2]**	*Remarks*
Blind position	Blind type				
Ref. Case 20% clr glass	NA	13566.4	2585.78	87.05	
Mid-pane	Venetian	11220.86	2645.81	76.13	
	Venetian-air flow	11437.09	2584.03	76.89	

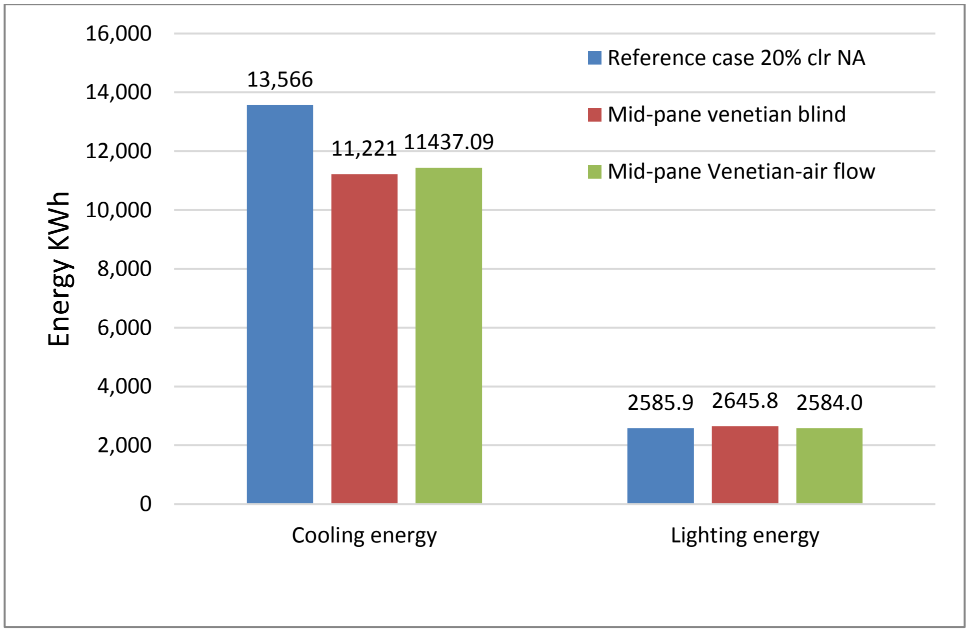

Figure 73. Annual cooling and lighting energy (kWh)

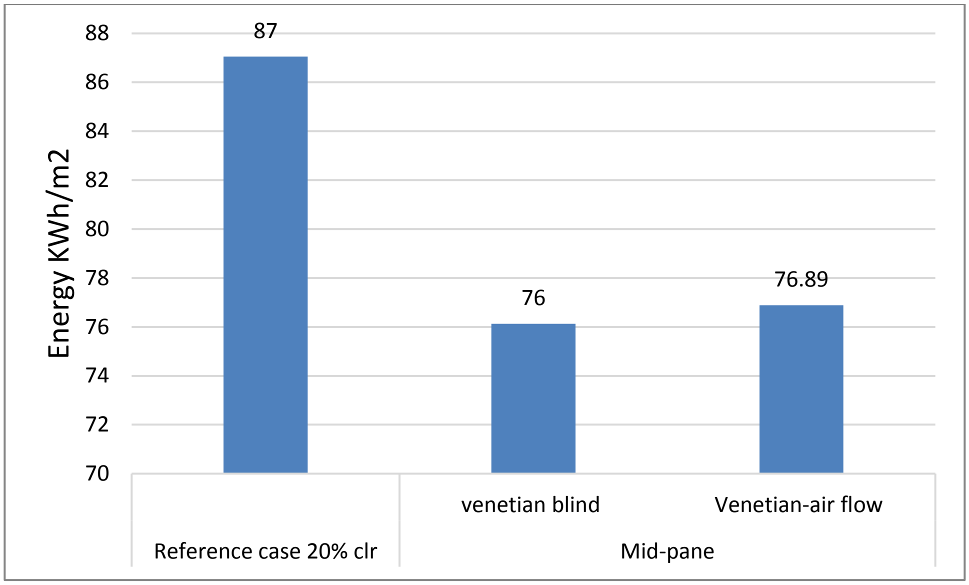

Figure 74 Annual Energy consumption (kWh/m2)

6.2.4 The impact of inside position of Window blinds (Venetian/ Role blind)

This study investigates two types of inside position of blinds. The venetian blinds and the role blinds.

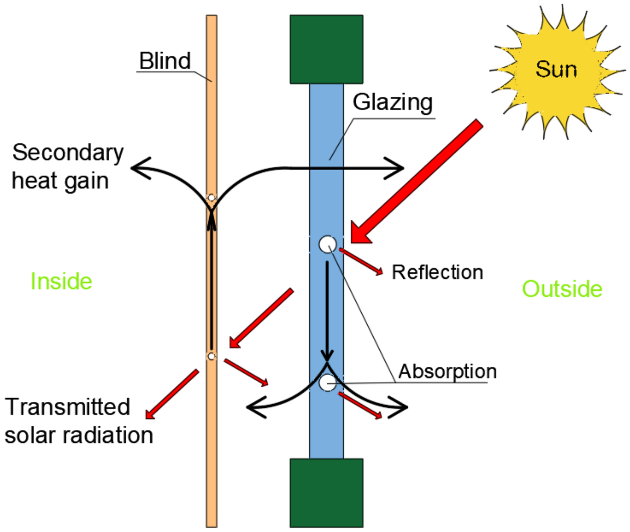

Figure 75 Schematic diagram of solar heat gain through window glazing and inside blinds.

Table 17 and figures (76,77) show that window blinds located inside the room has the lowest reduction of about 11% in energy consumption compare to the reference case of WWR 20% clear glass without blinds. There is no reduction found with the blind located inside the room if ignoring the contribution of low-e glass. Rather that, results show an increase in energy consumption when using the inside blinds. This is because the inside blinds work as a heat trap increasing the "greenhouse effect" inside the room and prevents heat from reaching the glass so that the process of heat conduction to outside is reduced.

Table 17: inside position of Window blinds

Double low-e- clear 20% glazing					
Independent variable		*Cooling energy*	*Lighting energy*	**Energy Per Total Building Area [kWh/m2]**	*Reduction*
Blind position	Blind type				
Ref. Case 20% clr glass	NA	13566.4	2585.78	87.05	--
Inside the room	Venetian Blind	11719.31	2577.75	78.25	10%
	Role blind	11593.30	2597.92	77.73	11%

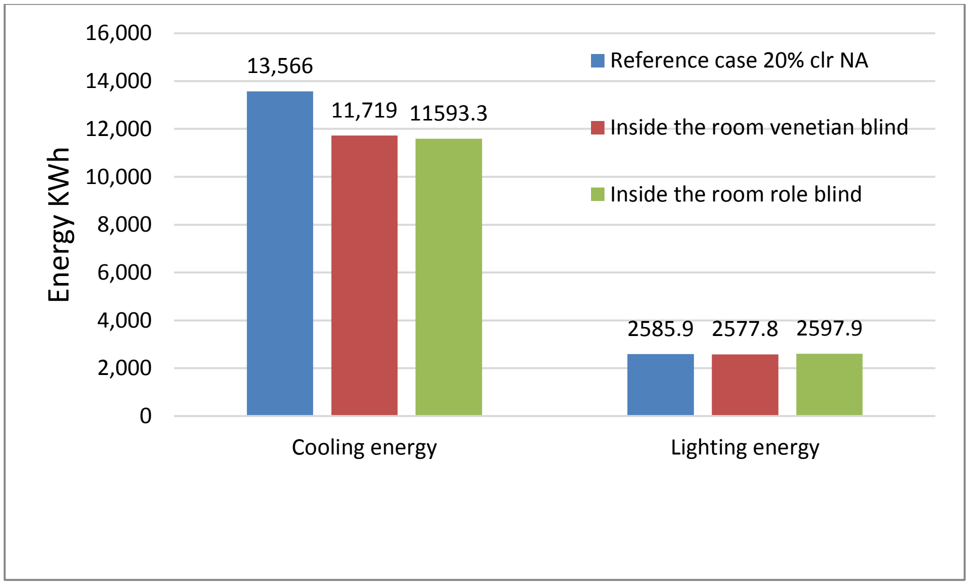

Figure 76 Annual cooling and lighting energy (kWh)

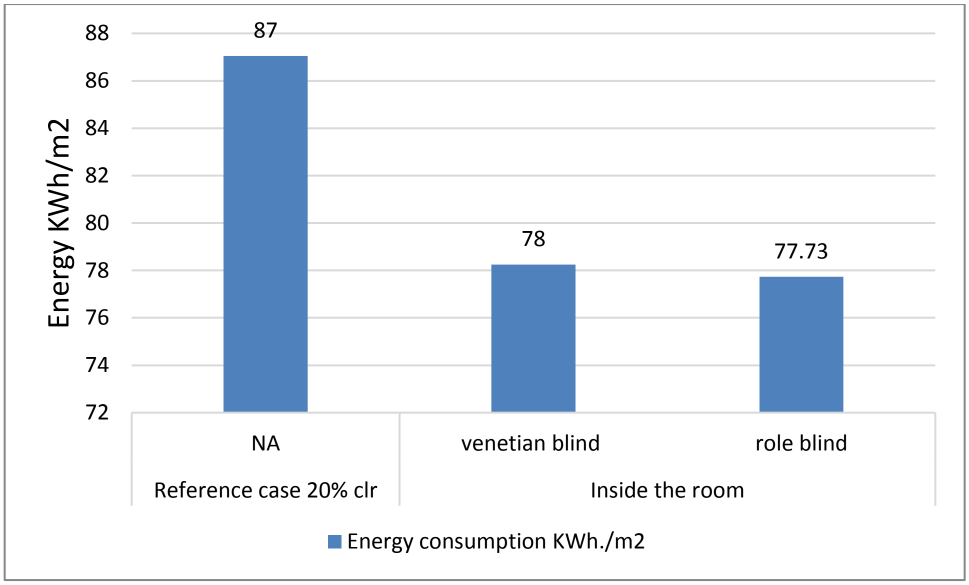

Figure 77 Annual Energy consumption (kWh/m2)

6.2.5 The impact of Switchable Window blinds

Electrochromic glass (smart glass or dynamic glass) is an electronically tin table glass used for windows, skylights, facades and curtain walls. Electrochromic glass, which can be directly controlled by building occupants, is popular for its ability to improve occupant comfort, maximize access to daylight and outdoor views, reduce energy costs and provide architects with more design freedom. Table 18 and figures (78&79) illustrates that this type of window shading has a useful reduction in energy consumption with about 16% compared to 20% WWR clear glass.

Table 18: reference case and Electrochromic.

Independent variable		***Cooling energy***	***Lighting energy***	Energy Per Total Building Area [kWh/m2]	***Reduction***
Case	Blind type				
Ref. Case 20% clr glass	NA	13566.4	2585.78	87.05	---
Electrochromic	Switchable	10822.78	2599.34	73.93	16%

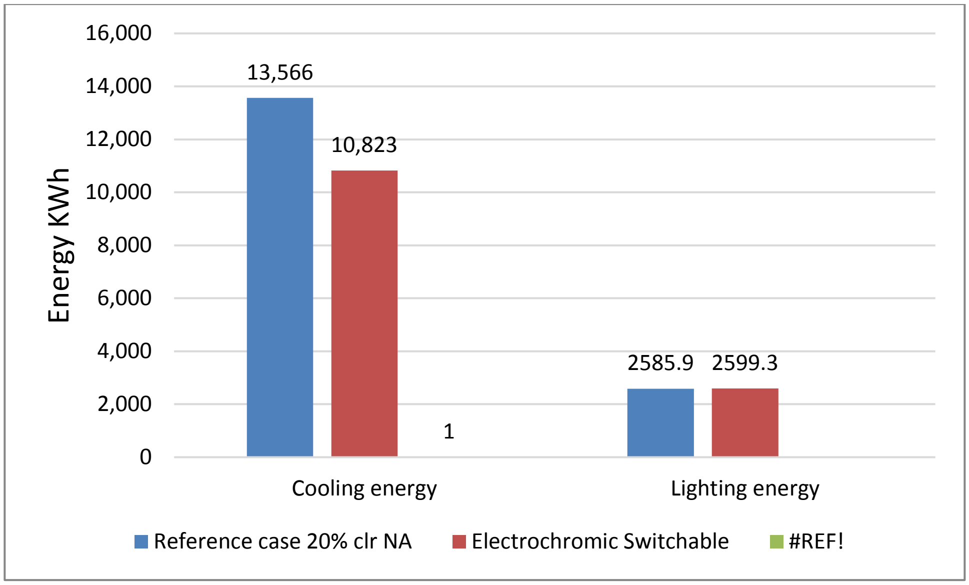

Figure 78 Annual cooling and lighting energy (kWh)

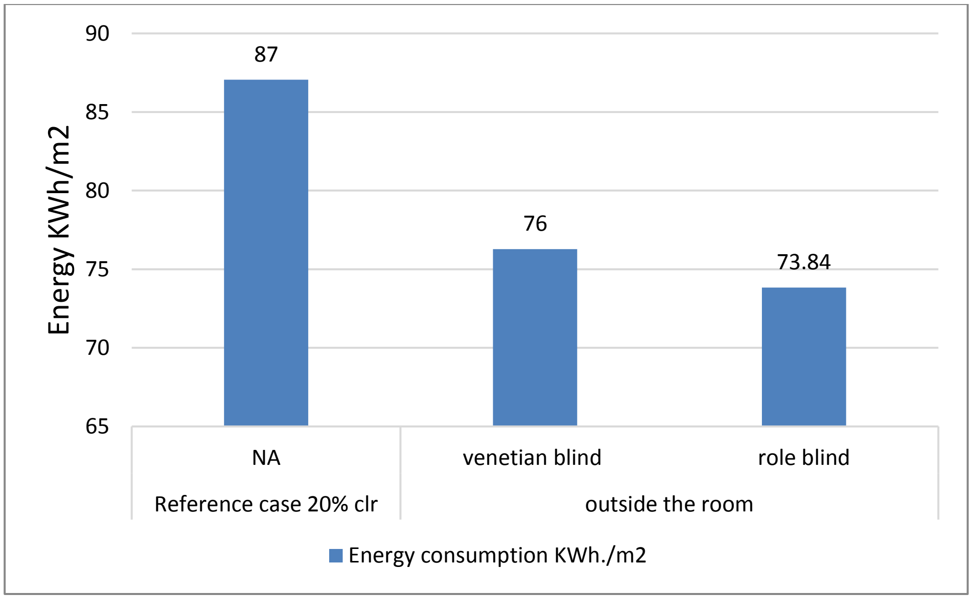

Figure 79 Annual Energy consumption (kWh/m2)

Table 19 and figures (80,81&82) summarizes the result of all cases. The window with low-e glass and role blinds located outside the window has a higher reduction in energy with approximately 16% compare to a reference case of clear glass with 20% WWR. Electrochromic window shading shows a similar result of 16% reduction in energy consumption. It is clear that inside window position is the worst case that shows no contribution in reducing energy consumption compare to the other window blinds position. This is due to direct solar radiation has already entered the room, then far-IR radiation that reemitted from the interior surfaces trapped indoor. The inside blinds besides the glazing reduces heat conduction to outdoor. The blinds cannot reach the glazing surface to pass through the glass. However, internal blinds are preferable to reduce glare and privacy revelation.

Table 19: brings together all the previous cases.

Independent variable	**EXPERIMENTS**	***Dependent variable*:**			***Reduction compare to RC***
		Cooling energy	***Lighting energy***	**Energy Per Total Building Area [kWh/m2]**	
Clear single glass	6% glazing-BC	9066.78	2,623.77	65.37	
	10% glazing	10,010.96	2,587.96	69.86	
	15% glazing	11232.78	2561.88	75.77	
	Reference case 20% glazing RC	13566.42	2585.78	87.05	
Double low-e-clr	20% glazing	11783.48	2615.14	77.85	11%
outside	**Venetian**	11317.03	2579.47	76.27	12%
	Roll	10805.21	2599.71	73.84	16%
Mid-pane	**Venetian**	11220.86	2645.81	76.13	12%
	Venetian-air flow	11437.09	2584.03	76.89	11%
Inside	**Venetian**	11719.31	2577.75	78.25	10%
	Roll	11593.30	2597.92	77.73	11%
Electrochromic Switchable	**Switchable**	10822.78	2599.34	73.93	16%

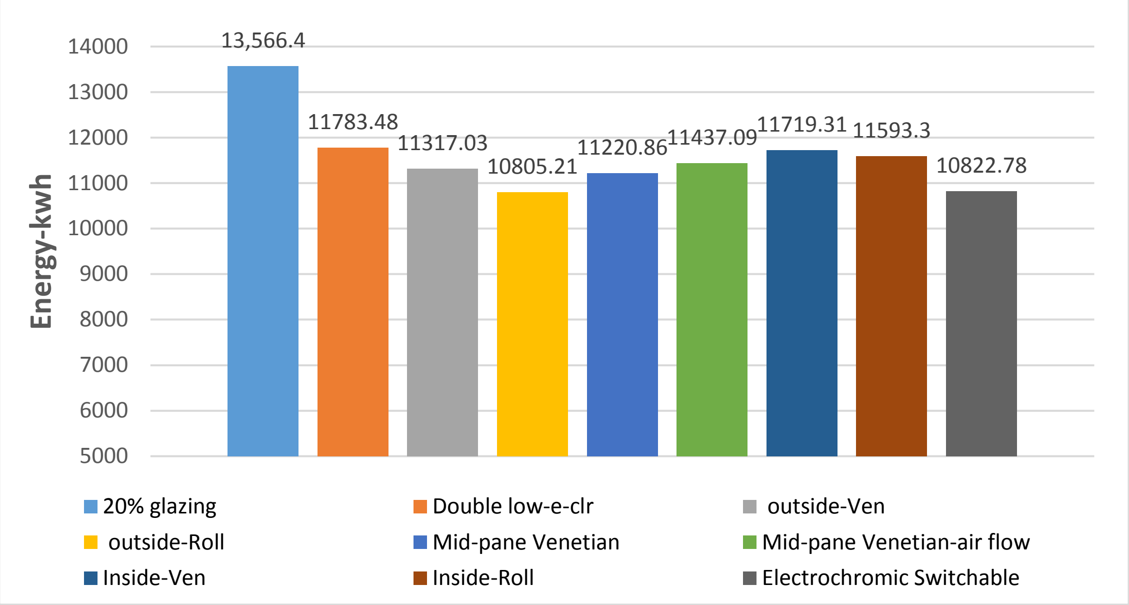

Figure 80 Annual cooling energy (kWh)

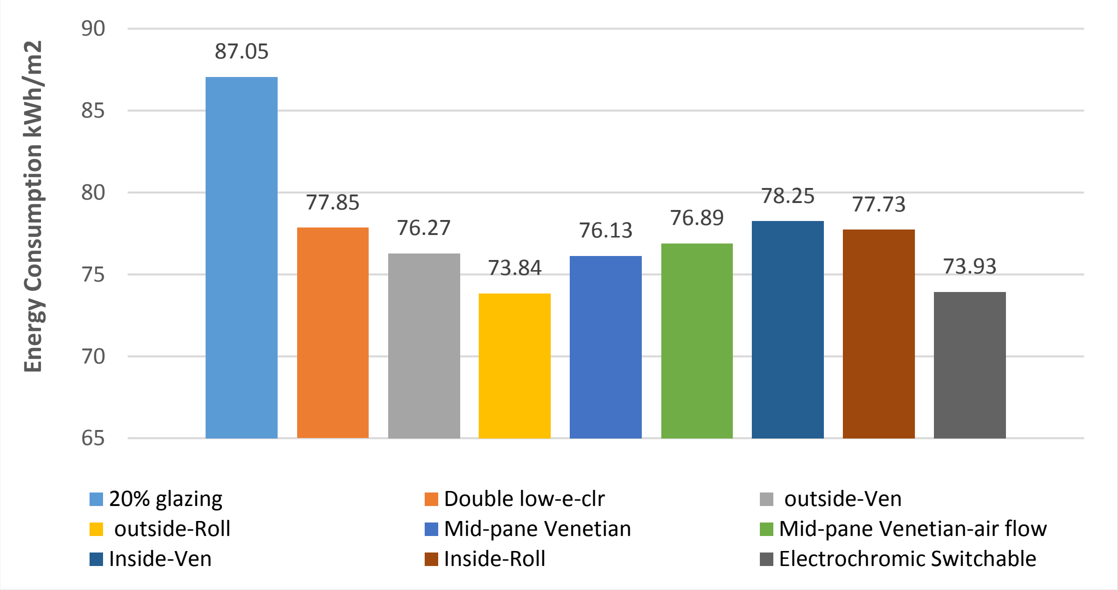

Figure 81 Annual Energy consumption (kWh/m2)

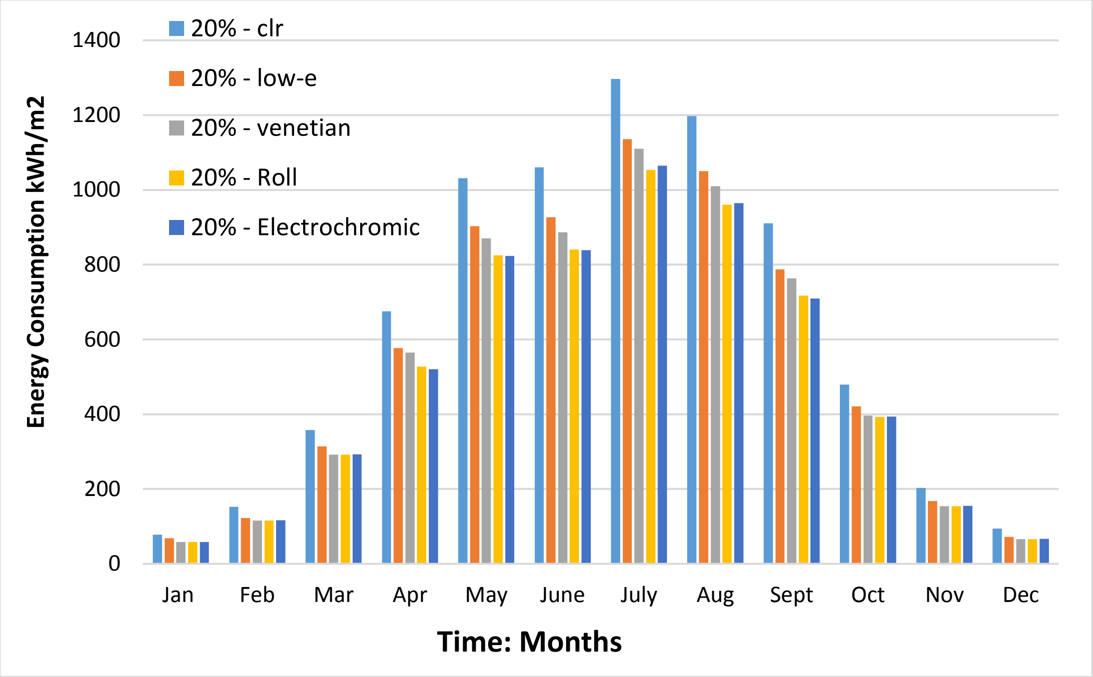

Figure 82 Energy consumption per month

6.3 Further discussion

The value of reducing energy consumption with the use of blinds appeared in the results as it is not significant compared to the reference case. This is because the window openings for which blinds were used are only few in the east and west facades. In addition, the simulation was run for the whole year, including the months when the thermal loads are low.

Moreover, figure (83) compare the investigated cases in a bedroom with a window facing west and the operation of air condition as set earlier for bedrooms. this figure is to confirm differences between all cases in terms of heat gain. It's clear from the figure that Venetian blind indoor show the worst case in terms of indoor temperature. whereas low-e without any blinds showing the lower air temperature indoor. It's also noted that the role blinds located outside the window has a good performance in terms of heat gain.

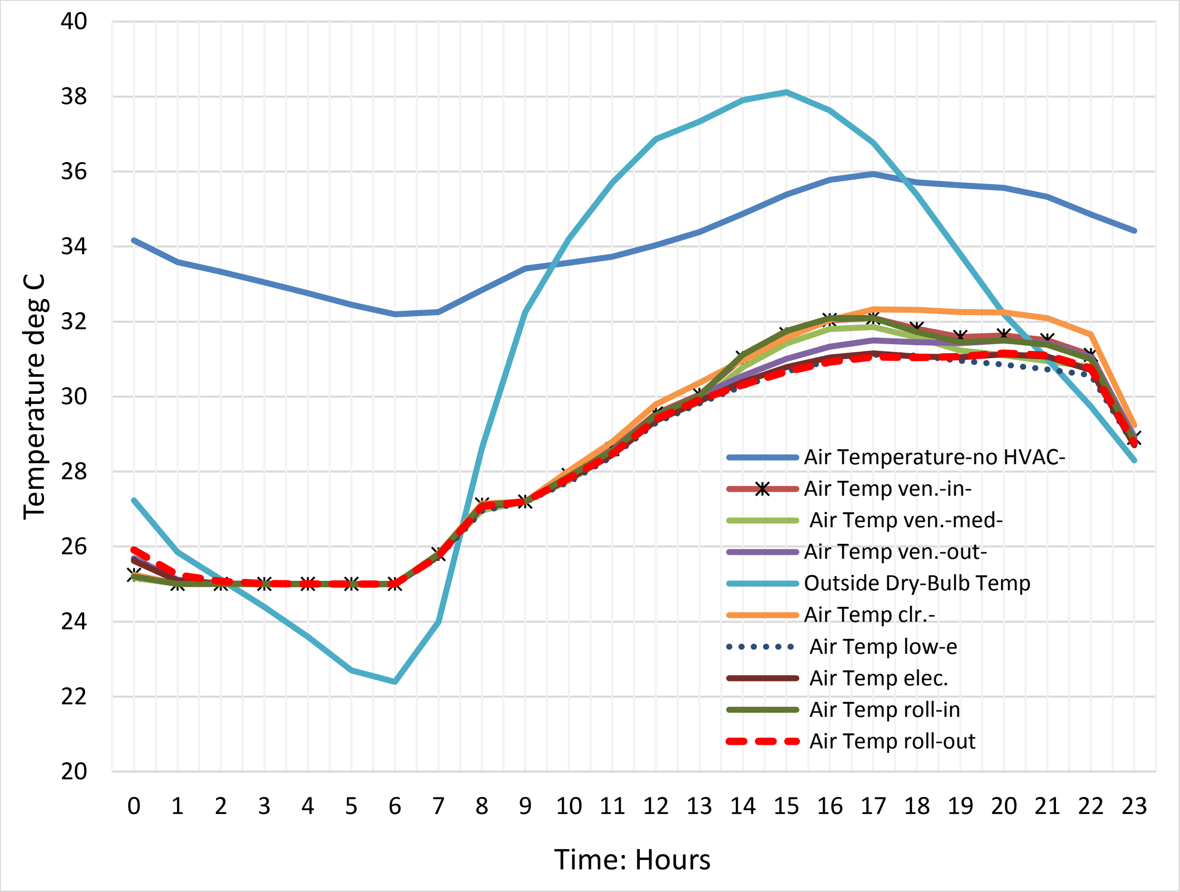

Figure 83 Thermal performance of different window blinds.

CHAPTER 7

CONCLUSIONS & RECOMMENDATIONS

This study concentrates on an existing building and future designed buildings. A simulation of an existing building was done to find solutions for the window so that it would be a smart and energy efficient windows. The aim is to balance between obtaining natural lighting, outdoor-connection and protecting the building from heat. The study started investigating the residents in Najran city to stand on their preferences. A questionnaire was distributed randomly in Najran city, and the number of respondents to this questionnaire was (146 people). The most important points emphasized by the questionnaire are the residents' preferences for natural lighting and a large window size.

Electrical bills of numbers of residential buildings in Najran city was investigated as well. The average energy consumption was found approximately 63.42kwh/m2, so that simulation was calibrated based on this value.

In achieving the main objectives, the study simulated a selected villa and examining the Impact of window- blinds, their type and position, on energy consumption of a simulated villa. Making the blinds as useful solution, the study first suggests a Clear Low-e glass to replace the current wired-glass for outdoor connection and heat control. WWR of 20% instead of 6% to enhance the building daylighting. The study suggests an operation scheduled of window blinds to enhance energy savings. It was to shade the windows with selected blinds when the direct solar radiation incidents on the window glazing.

The study suggests dynamic solution to shade the window when it is required to be shaded. Low-e glass is used to shade window from the outdoor high air temperature, while window blinds is to block direct solar radiation.

Comparing all types of blinds that were applied in this study against a clear-low-e glass, the study concluded the followings:

- The outside one found that roller blinds are better than venetian blinds in reducing energy consumption by about 3%.
- Venetian blind in between the glazing of the window make a minimal contribution to the reduction of energy cooling of about 1%. Integrating this system with airflow does not show any useful contribution as well.
- Window blinds located inside the room has the weakest performance in terms of energy reduction compared to the other blinds positions. Comparing inside-blinds to the reference case of WWR 20% clear glass, the energy consumption was reduced by about 10%. However, this 10% is due to the low-e glazing.
- Smart blinds like Electrochromic makes a useful reduction of about 16% compared to the reference case.

Operation schedule of HVAC system make a contribution to energy saving as this study sets the logical and practical HVAC schedule before starting the simulations, to match the average of the collected electricity bills.

7.1. Recommendations

- The study recommends using low-e glass so that controlling heat gain due to the variation between outside and inside. This makes a significant reduction in energy consumption.
- The study recommends using window blinds for building that has a daytime activity such as offices and Scholes. This is because the blinds show more effectiveness during the daytime.
- For further research, the following is recommended:
  - The study suggests that the impact of other types of blinds and glass be studied.
  - Testing the sunblock's in the north and south facades and their effect with the rest of the curtains in the building to achieve satisfactory results to reduce energy consumption.
  - This study also recommends spreading the window culture, expanding it and linking it to smart systems in buildings that help protect the privacy of the building occupants and allow them to communicate with the outside world and protect the building from thermal transfer.
  - Urging to conduct accurate scientific research that includes topics that help reduce consumption and provide comfort for residents

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